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Environmental Assessment of the Alaskan Continental Shelf

Final Reports of Principal Investigators
Volume 7. Biological Studies

U.S. DEPARTMENT OF COMMERCE
National Oceanic & Atmospheric Administration
Office of Marine Pollution Assessment

U.S. DEPARTMENT OF INTERIOR
Bureau of Land Management

February 1981

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I

The facts, conclusions and issues appearing in these reports are based on interim results of an Alaskan environmental studies program managed by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) of the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce, and primarily funded by the Bureau of Land Management (BLM), U.S. Department of Interior, through interagency agreement.

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Volume 7: Biological Studies

This is the first of a two volume* final report for:

RU#	INVESTIGATOR(S)	AGENCY	TOPIC
467	Steven R. Johnson J.W. Richardson	LGL Ecological Research Associates, Incorporated	Beaufort Sea-Barrier Island-Lagoon Ecological Processes Studies: Final Report, Simpson Lagoon

Table of Contents

SECTION	TITLE	AUTHOR(S)	PAGE
	Abstract		2
	Acknowledgements		7
PART 1	Program Background and Planning	Joe C. Truett, Benny J. Gallaway, D. Alan Birdsall	9
PART 2	Physical Processes	Joe C. Truett	52
PART 3	Birds	Stephen R. Johnson W. John Richardson	109
PART 4	Fish	P. C. Craig L. Haldorson	384

* Volume 8: Biological Studies is the continuation of this Final Report and contains the following sections:

Invertebrates
Primary Production and Nutrients
Synthesis, Impact Analysis and a
Monitoring Strategy

BEAUFORT SEA BARRIER ISLAND-LAGOON ECOLOGICAL PROCESS STUDIES: FINAL REPORT, SIMPSON LAGOON

RESEARCH UNIT 467

By

LGL Ecological Research Associates, Inc.

and

LGL Ltd.
Environmental Research Associates

To

Arctic Project Office
Geophysical Institute
University of Alaska, Fairbanks

For

Contract No. 03-6-022-35193
National Oceanic and Atmospheric Administration,
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ABSTRACT

In 1976 LGL Ecological Research Associates (LGL) was awarded a contract by the Outer Continental Shelf Environmental Assessment Program of the National Oceanic and Atmospheric Administration (NOAA-OCSEAP) to plan and implement an integrated ecological study of a barrier island-lagoon system in Alaska's Beaufort Sea. In conjunction with several university scientists, including a modeling team from the University of British Columbia, the study was planned in detail in mid- and late 1976. This report describes the planning, research, and results of that study in the 3½ years since it began.

The geographical location of the study was the Simpson Lagoon-Jones Islands area and vicinity. The subject focus was on geological, oceanographic, and ecological processes that supported vertebrate species of primary interest to humans, and that were speculated to be vulnerable to petroleum development activities. A number of findings of the study had important implications to assessing the consequences of man's activities in the area.

Physical processes studied included formative mechanisms of coastal landforms, water circulation and exchange patterns, and transport and delivery patterns of materials carried by the water. Submergence of coastal landforms and the consequent formation of lagoons from lake beds, and islands from coastal ridges, appears to dominate in shaping the coastal substrates. The erosional forces of water and ice, coupled with relatively slow longshore transport of sediments, further mold and change the emergent and submergent landforms. Circulation and the associated transport of entrained material is dominated by rapid longshore water motion; exchange between nearshore and offshore water masses is more restricted. However, the nature of the nearshore-offshore exchanges appears to be ecologically very important, in that these exchanges probably promote the accumulation of nutrients, detritus, and invertebrates in the nearshore zone.

Important bird species in the coastal environment include oldsquaw ducks and red and northern phalaropes. These feed mainly on crustaceans; oldsquaws eat mostly mysids, and phalaropes eat in addition large amounts of copepods. The activities of these birds are largely restricted to

the shallow bays, lagoons, and beaches from mid-summer to early fall (oldsquaw) and in August (phalaropes). These birds use the nearshore environment mostly for resting, feeding, and (for oldsquaws) molting, but not for nesting. Their main vulnerability to man's activities would probably be to oil on the water and beaches in late summer or early fall. Additionally vulnerable to man's activities would be island-nesting species (eiders, brant, snow geese), that occur in the region in small numbers.

The most important fish species are anadromous (arctic and least cisco, arctic char); of lesser direct importance to man but important ecologically, are some marine species (arctic cod, fourhorn sculpin). Similarly to the birds, all these species feed largely on epibenthic crustaceans--primarily mysids and secondarily amphipods. The anadromous species, abundant in the nearshore only during the warmer season, concentrate in the shallows near the margins of the mainland and, to some extent, near the islands. The marine species show less restriction in habitat preference; one of these species (arctic cod) is highly mobile and the other (fourhorn sculpin) is relatively sedentary. All the anadromous species are highly mobile. None of the important fish appear to use the nearshore environment for spawning, but apparently come there to feed and grow. These fish would probably be relatively resistant to being adversely affected by most of the anticipated activities of man, except for possibly the construction of extensive solid-fill causeways and the effects of increased harvests by commercial or subsistence fishermen.

Invertebrates were considered important in proportion to the extent that they were important as food for fish and birds. Thus, mysids and amphipods became the focus of interest. It appears that these epibenthic invertebrates acquire most of their nourishment from marine-derived recent primary production (as opposed to terrestrially-derived recent production or the abundant peat detritus in the system). Amphipods occupy both the lagoons and adjacent oceanic waters year-round; mysids leave the lagoons in late winter but repopulate them each summer. Most of the cropping of these invertebrates by fish and birds occurs in the shallow lagoons and bays in summer. There appears to be a superabundant production and availability of these invertebrates relative to the dietary needs of the fish and birds. The effects of man's activities on invertebrates would probably be detrimental to birds and fish only if (1) mysids were prevented from annually repopulating shallow lagoons where birds and fish feed or (2) very large scale decreases in the productivity of the invertebrates were caused by oil spills or other perturbations.

Primary production in lagoon and ocean waters, and not terrestrially-derived detritus, appears to be the major fuel of the food webs that support fish and birds in the nearshore environments. The major contribution to this primary production is thought to be by plankton (primarily diatoms) in the water column in summer, but a major secondary source of production is by epontic (under-ice) algal communities. Benthic primary production is thought to contribute a small portion of the total production to the food web. Primary production is highest per unit water volume in the nearshore shallows, apparently because the limiting nutrients nitrogen and phosphorus are optimally available there. The majority of nitrogen appears to come from the land and the major supplies of phosphorus are contributed by the ocean. The primary producers in general are suspected to be very resilient to oil spills and other perturbations, at least resilient to the extent that impacts would not be felt by fish and birds at the top of the food web.

In general, the nearshore environment of the Beaufort Sea appears to be highly productive (in terms of the biota of interest to man) relative to the adjacent ocean. Productivity is enhanced by (1) circulation that causes nutrients and biological products to accumulate in the nearshore, (2) shallow depths that promote rapid utilization of nutrients and biota, (3) short food webs that promote efficiency in net production, and (4) migrant populations of biota that populate the shallows during growth and feeding stages of their lives.

Ecological theory and data from this study suggest that the nearshore Beaufort Sea ecosystem should be extremely resilient to man-induced perturbations, especially when these perturbations resemble those caused by naturally-occurring events. We suspect that direct impacts on fish and birds (e.g., overharvests of fish, effects of oil spills on birds) will be more likely to manifest themselves than will indirect impacts caused by perturbations to food webs and habitats. It is strongly suggested that monitoring programs to be used to assess impacts as development proceeds be structured to measure the health of selected organisms and critical interactions between organisms and processes, rather than to measure the status of the species themselves.

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TABLE OF CONTENTS

Page

SUMMARY 11

ACKNOWLEDGEMENTS 12

INTRODUCTION 13

  General Nature and Scope of Study 13

  Objectives and Rationale 14

  Relevance to Impact Assessment 15

STUDY AREA: SELECTION AND CHARACTERISTICS 16

  Selection 16

  Characteristics 18

RESEARCH 20

  Program Management and Planning 20

  Chronology of Events 20

  Function of Workshops 22

  Definition of Research Tasks 23

  Use of Modeling 24

  The Workshop Simulation Model 26

    Space and Time Problems 26

    Model Description 29

APPENDIX 38

SUMMARY

The Barrier Island-Lagoon Ecological Process Studies Program was initiated in spring 1976. Most of the first year of the program was allocated to planning and designing the research to be performed in the next three years of the program. During this first-year planning period, the Simpson Lagoon-Jones Islands area was selected as the study site, and biologists, chemists, oceanographers, and geologists were selected to carry out disciplinary studies. The studies to be performed were to focus on the physical and biological processes rather than on components alone.

The important features of the research design efforts were several:

1. The research needs were determined largely by biologists because the focus of interest was on biological components (species) that depended on selected processes.
2. The direction of research was focused sharply by the mandate to examine only selected animal species and the processes and habitat components that regulated these species in important ways.
3. The major integrative force of the program was the interactive planning that took place at semi-annual workshops where all principal investigators convened to plan research and to evaluate existing data.
4. Ecosystem modeling exercises were used as the major tool during the workshops to identify existing data gaps and to guide research to fill these gaps.
5. The simulation model that was used had as its main purpose the quantitative evaluation of the current concepts of the investigators as to how the system functioned. It was obliged to deal with an array of problems, including congruence in space and time among disciplines and between field sampling and model representation, and appropriate representations of the system's integrity in space.
6. Four submodels were constructed and periodically revised by assembling information from four disciplinary panels of workshop participants. A description of these submodels is presented, and a copy of the FORTRAN code of the latest version of the ecological portion of the simulation model is appended.

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INTRODUCTION

Early in 1976, the Research Planning Committee of NOAA's Outer Continental Shelf Environmental Assessment Program (NOAA-OCSEAP) sent selected research organizations a request for a proposal to develop an interdisciplinary ecological process study in a coastal area of the Alaskan Beaufort Sea. The study was to be conducted in two distinct stages: an in-depth information review and research planning stage, which would be followed by an active research program to collect and integrate the existing data and to conduct new field research. In May 1976 a contract was awarded to LGL Limited-U.S., Inc. (now LGL Ecological Research Associates [LGL]) to develop a research plan (Phase I), and subsequently to conduct the planned research (Phase II).

General Nature and Scope of Study

This program was designed to be a closely-integrated research investigation of the physical and biological processes in a barrier island-lagoon system on the Alaskan Beaufort coast. (Processes, broadly defined as the patterns of change that are governed by natural laws and that recur in time and space, are exemplified by such phenomena as water circulation, land-form erosion, sediment transport, and migration and feeding activities of fish and birds.) The program was to identify the processes that are sensitive to impacts and important to those ecosystem components (organisms) that are of particular concern to society; these processes were to be studied as a means of assessing the impacts of development upon these components. A significant factor that affected the research program was the need to extrapolate the approach and findings of the study to assist in the assessment of impacts in other areas of the Beaufort Sea continental shelf.

At the outset NOAA-OCSEAP identified the general types of processes in the barrier island-lagoon environment that they viewed as important in the context of the objectives of the program, and that they therefore required to be studied. These were processes that related to (1) the biology of the system, (2) the oceanography and nearshore circulation, and (3) the dynamics of the coastal land-form features (geology). The disciplinary limits of the program were thereby established, and this permitted the subsequent selection of qualified specialists as principal investigators to design and implement the appropriate studies. Subsequently during the course of research planning, specific processes which were to be studied within each discipline were identified.

Objectives and Rationale

Because this program was, in essence, an experimental undertaking, an implied objective of the program was to test the viability of the process analysis approach to impact assessment. Three more specific research objectives of the program were stated by NOAA; these objectives and an amplification of each are as follows:

1. *To identify and analyze those components and processes that contribute significantly to the structure and productivity of the nearshore ecosystem.*

   It would be impossible to study all of the components and processes that occur in the barrier island-lagoon ecosystem. The scope of this objective was accordingly narrowed during the course of the research planning to include only the identification and analysis of those systems processes (and their associated components) that were essential to the life-support of the species that had been identified as "important" and that were likely to be altered as a consequence of development. "Important" species were defined to be those birds, fish and/or mammals that were a significant constituent of the fauna of the area to be studied and that (1) had significant commercial or recreational value, (2) were important to the subsistence of local residents, and/or (3) were otherwise "high profile" and therefore of major concern to society and to decision-makers. Modifications to the list of important components and processes were made as a consequence of findings made as the study progressed.

2. *To evolve mechanisms whereby the "important" components and processes can be evaluated for their reaction to man's activities.*

   Most impact assessments have been based on speculation that is tied to established facts. The purpose of this objective was to make this process more accurate. This objective would be addressed by the generation of a series of hypotheses that would be capable of being tested, that would be relevant to impact assessment, that would be cost-effective from the point of view of impact assessment, and that could ultimately lead to more accurate speculation about the consequences of development.

3. *To determine the feasibility of detecting and quantifying the temporal changes in "important" ecosystem components and processes.*

   Testing of hypotheses about reactions of ecosystem components and processes to man's activities usually requires quantification of change. Changes in values or levels of ecosystem components or in the rates at which processes occur are normal, even in the absence of man's influence. Changes caused by human activities thus are often difficult to separate from normal temporal variations. In order to determine whether a specific component or process can be used to measure impact, it is essential to determine the feasibility of measuring changes in the component or process with sufficient precision to quantify both the normal range of variability and the perturbations of such normal variability that are caused by man.

Relevance to Impact Assessment

System processes differ from components in two ways that relate to impact analysis; each of these ways offers an advantage over conventional methods of impact assessment (i.e., assessment via baseline studies of components):

1. Man's activities sometimes assert themselves as impacts through alteration of support processes rather than through direct obliteration of components (populations). A characterization of process rates and mechanisms, rather than a compilation of baseline data about components, will therefore enable scientists to speculate more effectively about the manner in which development may alter the important components.
2. It has been hypothesized that the characteristics of processes are temporally and spatially more conservative than are characteristics of components. As a result of this relative constancy the process information is more broadly applicable than is conventional baseline data, and may consequently be more freely extrapolated to answer questions about development impacts in other areas.

STUDY AREA: SELECTION AND CHARACTERISTICS

Selection

The NOAA-OCSEAP planners desired that the Barrier Island-Lagoon Study focus its attention on a representative barrier island-lagoon site on the Alaskan Beaufort Sea coast. Ideally this site would have the following characteristics:

1. It should, as much as possible, typify other barrier island-lagoon systems so that data from other areas that applied to the processes under consideration could be used in the study and so that research findings from this study could be extrapolated to other areas.
2. It should have been comparatively little disturbed by past human activities, so that the processes to be studied would be representative of a relatively "natural" situation.
3. It should be relatively accessible in order to minimize logistics support costs.
4. It should have previously been the focus of research so that a partial data base would already be available.

Four areas along the Alaskan Beaufort Sea coast were initially evaluated as potential study sites. Considered as candidates were Elson Lagoon and the Plover Islands (in Naval Petroleum Reserve No. 4), Simpson Lagoon and the Jones Islands (about 30 km west of Prudhoe Bay), Challenge-Flaxman Lagoon and the Maguire-Flaxman Islands (near the Canning River delta), and Kaktovik Lagoon and Barter Island (in the Arctic National Wildlife Range).

The Simpson Lagoon-Jones Islands area (Fig. 1) was selected over the other areas for several reasons, including the variety of habitat types that the area appeared to contain relative to the diversity found at other sites, its nearness to efficient logistics support, and the amount of background data available for the site.

Because of the extreme variability among the physical parameters from place to place along the Alaskan Beaufort Sea coast, it became obvious that no system could be considered "typical". The selected area appeared to be relatively heterogeneous with regard to its physical

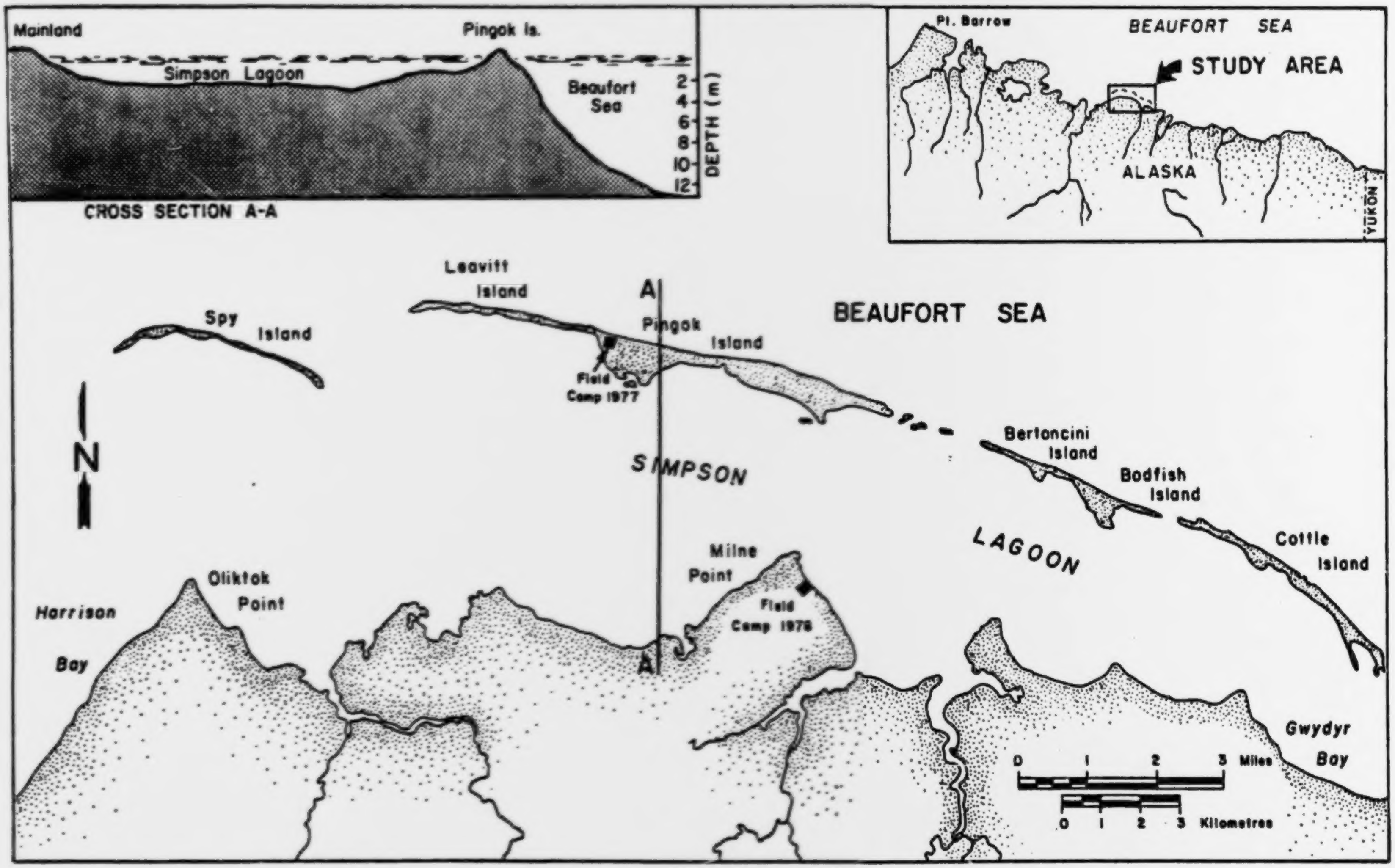
Mainland
Pingok Is.
Simpson Lagoon
Beaufort Sea
2
4
6
8
10
12
DEPTH (m)
CROSS SECTION A-A
Pt. Barrow
BEAUFORT SEA
STUDY AREA
ALASKA
YUKON
Leavitt Island
A
Spy Island
Pingok Island
BEAUFORT SEA
Field Camp 1977
N
SIMPSON
Bertoncini Island
Bodfish Island
LAGOON
Cottle Island
Milne Point
Oliktok Point
Harrison Bay
Field Camp 1976
A
Gwydyr Bay
0 1 2 3 Miles
0 1 2 3 Kilometres

Figure 1. Simpson Lagoon study area on the Beaufort Sea coast of Alaska.

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characteristics. It contained elements that seemed representative of the variety that exists along the northern coastline of Alaska; in this respect it may be of more value than a relatively homogeneous site. By addressing the diversity of physical habitats available for study at Simpson Lagoon, greater potential existed for extrapolation of the data to a variety of coastline situations.

Although the extensive installations of the Prudhoe Bay oil Field are only a short distance (about 30 km) to the east of the area and a Distant Early Warning (DEW) station and air strip are located at Oliktok Point, no major communities or settlements are in the immediate vicinity of Simpson Lagoon. Several cabins (some seasonally occupied) and a landing area are present along the mainland coast of Gwydyr Bay.

Logistics problems for field studies appeared to be relatively minimal. The area is 30-40 km west of the Deadhorse jetport, which has both helicopter and fixed-wing aircraft support and scheduled air services from Fairbanks.

A considerable amount of scientific data was available for the Simpson Lagoon area on both its physical and biological parameters. A number of recent and on-going studies have been funded through state and federal organizations and by private corporations.

Characteristics

The major research effort was carried out in the immediate vicinity of Simpson Lagoon and the adjacent Gwydyr Bay; subsidiary sampling efforts were made as deemed appropriate in other adjacent areas. One river, the Ugnuravik River, discharges into Simpson Lagoon; two rivers, the Sakonowyak and the Kuparuk rivers (from west to east), discharge into Gwydyr Bay. The Colville River, to the west of the study site, and the Sagavanirktok River to the east exert a more peripheral influence on the system. Lagoon waters are up to approximately 4 m deep, but most are less than 2.5 m (Fig. 2). Prevailing currents are from east to west, but periodically reverse their course under strong winds from the west. Lagoon waters freeze to a depth of approximately 2 m by late winter, at which time under-ice salinities are very high (up to 60 ppt); salinities

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rapidly decline to brackish during the course of breakup in early summer, then gradually increase during the open-water season. Lagoon bottoms are silt or sand covered in deeper areas by a thin layer of detritus.

The mainland and the larger islands have a surface of tundra vegetation overlying peat deposits. Other islands are surfaced with sands and gravels.

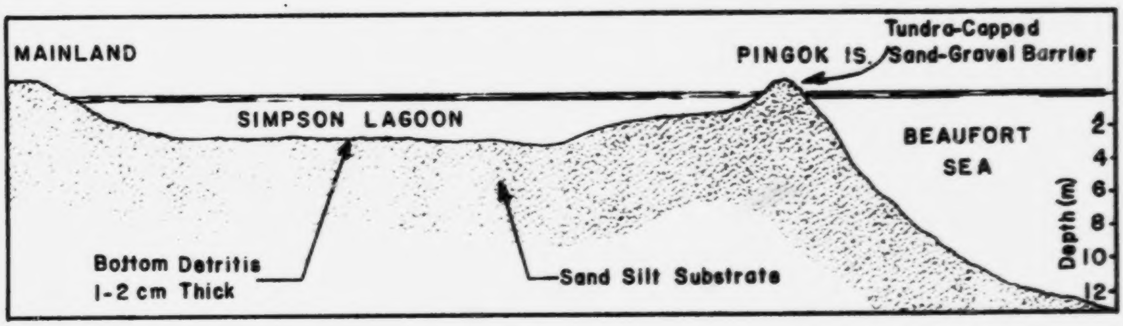
MAINLAND
PINGOK IS.
Tundra-Capped Sand-Gravel Barrier
SIMPSON LAGOON
BEAUFORT SEA
Bottom Detritis 1-2 cm Thick
Sand Silt Substrate
Depth (m)
2
4
6
8
10
12

Fig. 2. Cross section of Simpson Lagoon.

RESEARCH

Program Management and Planning

The Barrier Island-Lagoon Program was managed by LGL, which, in conjunction with its Canadian affiliate (LGL Limited), was responsible for the course and direction of the program since the award of the initial contract. As a first step in responding to the contractual requirement of detailed program planning, LGL developed the program framework and identified the general research needs.

Principal investigators for the various research fields that had been identified were selected from the staff of LGL and, on the basis of proposals submitted, from various universities (Table 1). With one exception, investigators with university affiliations came into the program under separate contracts with NOAA-OCSEAP; their annual reports are submitted separately according to the terms of their respective contracts. Dr. C.J. Walters et al. were under subcontract with LGL. Despite the contractual segregation among disciplines, however, the research data were shared among investigators.

Chronology of Events

Although the planning and research phases of the program have been contracted separately, the two emerged as one continuing effort. A discussion of the sequence of program events follows.

In June 1976 an initial background document was prepared; it outlined the proposed program within the context of a brief regional environmental description based on existing literature. This document was submitted to NOAA-OCSEAP and to other selected scientists for their information and review. In late July of that year a meeting was convened for a discussion of the incipient research plan. Attending were representatives from OCSEAP and from LGL, consulting scientists who had reviewed the above background document, and a systems modeler (Carl Walters) from the University of British Columbia. Following this preliminary planning workshop, and partially in response to ideas that were generated therein, a draft research plan was submitted to NOAA in September 1976. The

Table 1. OCSEAP research unit numbers, disciplines and affiliations of principal investigators participating in the Barrier Island-Lagoon Program.

Principal Investigators	Ru No.	Discipline	Affiliation
J.C. Truett	467	Project Director	LGL Ecological Research Assoc.
S.R. Johnson	467	Ecology (Birds)	LGL Ecological Research Assoc.
P.C. Craig	467	Ecology (Fish)	LGL Limited
W.B. Griffiths	467	Ecology (Invertebrates)	LGL Limited
C.J. Walters et al.	467	Systems Modeling	Univ. of Br. Col.
J.B. Matthews	526	Oceanography	Univ. of Alaska
J.C.H. Mungall	531	Oceanography	Texas A&M Univ.
P.J. Cannon	530	Geology	Univ. of Alaska
A.S. Naidu	529	Geology	Univ. of Alaska
D.M. Schell	527	Nutrient Dynamics/ Primary Production	Univ. of Alaska

draft plan was followed in October by a second draft that had been revised in response to comments from OCSEAP.

A first modeling and integration workshop was held on 2-4 December 1976 to assemble the principal investigators who had been identified prior to that time and to create a preliminary systems model on which to structure the forthcoming research program. As a result of that workshop and the associated modeling exercise, the research plan was further revised and was submitted to OCSEAP on 17 January 1977. Preparations were then begun for the research phase of the program. Final research plans for the first year's field work were completed during the course of a second modeling and integration workshop in April 1977.

Field research commenced in early May 1977 and extended to late September. Following a preliminary analysis of the season's research data, a third modeling and integration workshop was held on 6-8 December to revise the existing model using 1977 field research data, and to begin coordinated planning for 1978 research. Similar modeling workshop sessions were held again in 1978 to plan and evaluate the field research conducted in 1978. Workshops and extensive field research were discontinued in 1979, and preparation of this final report was begun.

Function of Workshops

Workshops have served as focal points for continued research planning. The workshops have functioned specifically to accomplish the following:

1. the promotion of general communication among principal investigators, project managers, and NOAA and BLM planners and administrators,
2. the provision of a mechanism for critical examination and revision of research task priorities,
3. the preparation and refinement of the computer simulation of systems processes,
4. the assembling of principal investigators prior to the field season to plan an integrated field research effort, and
5. the assembling of principal investigators following the field season to evaluate the research data collected.

Workshops were usually held at the University of British Columbia in Vancouver, B.C in December and in April of each year. The December workshops emphasized the preparation and updating of the simulation model (see 'Workshop Simulation Model' section to follow) and served to increase the general understanding of the research program and the system under study. Emphasis in the April workshops was on continued general communication, on a re-examination of research priorities in light of the most recently available information and on the planning of research activities for the coming field season.

Definition of Research Tasks

Definition of research tasks occurred largely at workshops. Biologists assumed the responsibility for establishing the general objectives of all disciplines, because selected organisms were the ultimate focus of interest. The non-biological disciplines functioned as internal service groups, and their research was designed to provide information that was needed by the biologists. The biologists specified the types of physical and chemical process information that they required in order to clarify the biological dependencies that they were to investigate. The oceanographers, geologists, and chemists then designed or modified their research plans to provide the biologists with these data.

The primary consideration in defining research tasks was to insure that the research efficiently addressed the ultimate goal of assessing the impacts on designated resource components ("key" species of animals). A structured approach for establishing research priorities at workshops was guided by the following concepts, some of which depart appreciably from convention.

1. System components (organisms) of particular interest to society were identified at an early stage. (These "components of interest" were found to be predators, which are situated ecologically near the top of the food chain.) Research efforts were thereafter directed solely toward clarifying the environmental dependencies of these organisms.

2. Food-chain and habitat dependencies of these predators were evaluated in a step-wise fashion that began with the predators themselves and moved down the food chain. (Conventional "ecosystem" studies have usually "looked upward" from the presumed energy base in an attempt to trace the food chain lines within an extremely complicated array of energy transfers, few of which directly regulate the vertebrate populations.) Because this method forced investigators to look at only those energy transfers and habitat-use factors that were necessary to the life-support of the "important" organisms, it promoted research efficiency.

3. Processes importantly affecting the organisms' food chains and habitats were identified. However, research was designed to address only those processes likely to be significantly affected by development activities. The most recently-available information on present-day OCS development technology was used to delineate which processes were likely to be affected.

Use of Modeling

A systems modeling team at the University of British Columbia provided a unique service to the Barrier Island-Lagoon Program. Through use of a computer simulation model of the system, they helped to establish an interdisciplinary communication format within which research planning (and evaluation of results) were facilitated. The functions of the modeling exercises were as follows:

1. *Construction of the simulation model.*

   The first function of the modeling workshops was to construct a simulation model. To do so, each disciplinary specialist explained to a modeler how the processes within his discipline operated and what information he required from other disciplines in order to predict the operations of processes within his discipline. The modeler then translated the description of these relationships into a series of equations, which formed the simulation model. Important gaps in the understanding of the system were revealed when the "current concepts" of the disciplinary specialists proved to be incomplete. This situation usually occurred when the model of the dynamics of a discipline required input that was not available.

2. *Organization of existing information and assessment of its completeness through operation of the simulation model.*

   Once the modelers had produced a functioning model that approximately simulated the "current concept" of the operations of the system, the existing data were organized and provided to the modelers and actual simulations of the system were run. The initial inability of the model to approximate the real system indicated to the disciplinary specialists and the modelers the presence of additional errors in their "current concept" of the system and pinpointed areas where the existing data were inadequate or inaccurate. On the first run of the model, for example, the lagoon quickly filled in with detritus and sediments. This process, whereby the model is repeatedly used to test the evolving "current concept" of the system, is the primary value of the modeling workshops as a research planning tool.

3. *Provision of a common focus for determination of research priorities.*

   It became evident at the outset that communication among disciplines was difficult because of differences among the scientists in their perceptions of the roles of their research and hence in their opinions concerning research priorities. The model forced the investigators to place all of the research needs in a common format that tended to reduce these differences.

4. *Definition of appropriate temporal and spatial limits to research.*

   Considerable effort was expended during the first two workshops to define the appropriate time scales for the research and modeling efforts, and to define the limits of the study area. With respect to the time scale, the effort was to determine the maximum time interval between samplings that would result in an acceptably low probability that an important change or event would be missed. Such a determination was necessarily a subjective determination; not surprisingly, different disciplines were found to require different time scales.

   It was important to define the study area so that the research could be applied to a system with some integrity. That is, the limits to the study area should be chosen such that, to the extent possible, the area is a logical unit wherein a maximum number of processes occur solely within the system and a minimum number and complexity of input and output phenomena cross the study area boundaries.

5. *Use of the simulation model to design research.*

   The sequence of steps followed to design research was similar at each workshop session. Following an initial exercise to precisely define the program goals (problem definition) and to identify the interdisciplinary information requirements, the development of quantitative submodels was begun. Four submodels were created or (at later workshops) refined; each simulated processes within a particular discipline (oceanography, geology, aquatic biology and ornithology). Once the submodels were connected into an overall computer simulation, the simulation was used to explore the sensitivity of the system to changes in the values and functional relationships that were assigned to important processes. If it was found that a small change in a particular variable or relationship resulted in a major impact on the way in which the model functioned, then that variable or process was considered to be of high priority in the research planning effort. Similarly, if it was found that the system did not respond over a wide range of values of a particular variable or over a variety of assumed functional relationships, then that variable or process was not considered to have a high priority.

The Workshop Simulation Model

Modeling workshops have filled a critical role in this project. At regular intervals, they have served as a focal point for quantitative evaluation of the current concepts of the investigators as to how the system works. Because those concepts have undergone substantial evolution during the project, the model that has been produced during the workshops has also changed several times. This section is intended to summarize those changes in the model so that the reader can understand some of the changes in understanding that have occurred during the project. A copy of the FORTRAN code of the latest version of the model is provided in Appendix 1.

Space and Time Problems

The first two workshops (November 1976 and April 1977) devoted considerable effort to defining appropriate temporate and spatial scales for the research and modeling efforts. Decisions were based on a variety of scientific and logistic criteria such as:

1. System Integrity. It was important to define the study area so that, to the extent possible, the area was a logical unit wherein a maximum number of processes occurred solely within the system and a minimum number and complexity of input and output phenomena crossed the study area boundaries.

2. Programming and Computer Capabilities. The size of the computer set an upper limit to the number of variables and the simulated time steps in the model. Trade-offs had to be made among the space and time dimensions of the model. For example, the model could simulate a spatially detailed view of the system for a small number of time steps or a spatially aggregated view for a large number of time steps. But it was not generally possible to model many variables over a large number of spatial areas or many time steps.

3. Congruence Among Disciplines. The time and space scales of the processes being investigated were often so much different that compromises and combinations of different scales were necessary. For example, it was difficult to capture the dynamics of plankton on a time step much larger than a day, but it was pointless to use a one-day time step for geological processes which evolve over decades.

4. Congruence Between Field and Model. Because the model was used for field research planning and evaluation of results, it was necessary that the time and space scales in the model be similar to the time and space scales for field sampling.

During the first workshop, three mutually exclusive options for space-time resolution of the initial model were identified:

1. IBP-style 'point' representation; representing a single onshore-offshore transect in great temporal detail.

2. An intermediate-scale representation of one short 5-km section of arctic shoreline and associated lagoon and barrier island area.

   This approach would have allowed some representation of the spatial heterogeneity along the lagoon shoreline, but would not have addressed large-scale geophysical and biological processes such as river runoff, erosion, and the migration of fish and birds. With this spatial scale, seasonal resolution of processes could have been achieved, but very short dynamic responses would have been poorly represented.

3. A large-scale representation involving one or more river mouth and Barrier Island complexes. This approach could have handled broad policy options (facility sighting, land and river impacts on migratory organisms) and spatial processes but would have required a very crude representation of short-term, small spatial processes and events.

In the first workshop, it was decided that option (2) might provide enough understanding of the seasonal and weekly processes to permit sensible development of a large-scale model in later workshops. It was decided to start with a model of a 5-km band of shoreline in the Simpson Lagoon area. Late in the first workshop, it became apparent that we were trying to deal with too small an area. Water movement simulations and animal dispersals indicated that the ecological dynamics of small areas in the lagoon were likely to be dominated by inputs (currents, migrations, sediment loads) from outside the model's boundaries. Water movements might transport planktonic communities dozens of kilometers per day along the Beaufort Sea coast, and epibenthic organisms might move large distances in short times. The first model also indicated that lagoon productivity might be driven by a small number of pulses of primary production and detritus inputs (at ice break-up and late summer). This assumption implied that long-term productivity and integrity of the lagoons might be determined by very short-term events and interactions at the boundary of the model.

In the second workshop, it was decided that the model should consider the whole of Simpson Lagoon as one well-mixed water unit and should predict ecological changes on a day-to-day basis over the summer ice-free season. Spatial heterogeneity was represented only in terms of the overall amounts of gross habitat types present in the study area.

The model currently simulates a 'year' of one hundred days. The first ninety days are divided into nine 'weeks' of ten days each, representing the spring, summer, and fall ice-free period. The final 'week' of ten days represents the winter.

There are thirteen habitats defined within the study area: island tundra, deep lagoon, shallow lagoon (protected), shallow lagoon (open), shallow lagoon (stagnant), low shoreline (mainland), high shoreline (mainland), pond-freshwater habitat, pond shoreline, inland polygons, inter-island open ocean, low shoreline (island), and high shoreline (island). The island tundra, pond-freshwater habitat, and pond shoreline habitats are not used in the most recent models that have concentrated on the lagoon and its shores.

Model Description

The logical structure of the model involves two computer programs, one for physical water movements (wind-driven currents) and one for ecosystem processes (transport of nutrients, organisms, materials, and biological interactions). The structure of the interaction of the two models is depicted in Fig. 3. The water movement simulation model is used to estimate the wind-driven currents in Simpson Lagoon. These estimates are made under a variety of wind directions, speeds, and morphological configurations of the lagoon (causeways, artificial islands). The current velocity estimates from the physical simulation are used in the ecological model to determine the flushing rate of the lagoon and to estimate the transport of organic and inorganic materials, epibenthic and planktonic organisms into and out of the lagoon.

Subsystem Modeling Approach. The ecological model is divided into four submodels. Originally, the arrangement of disciplines into these submodels was designed to provide an even workload for the modeler programming each submodel. However, the relative importance of the submodels has changed so that the aquatic biology submodel now includes a majority of the interesting dynamics in the model.

The Physical Oceanography Model. Most of the physical data used in the ecosystem model are derived from the results of a two-dimensional numerical water circulation model written by Dr. J.C.H. Mungall and applied to the lagoon. This physical model predicts depth mean currents that result from the application of surface stresses caused by a specified wind. Average nearshore and mid-lagoon currents and the rate of flow of water through the lagoon are also generated. The grid intervals used in this physical model are 1 km (Fig. 4). To obtain these estimates quickly and cheaply, the depth throughout the entire model region is

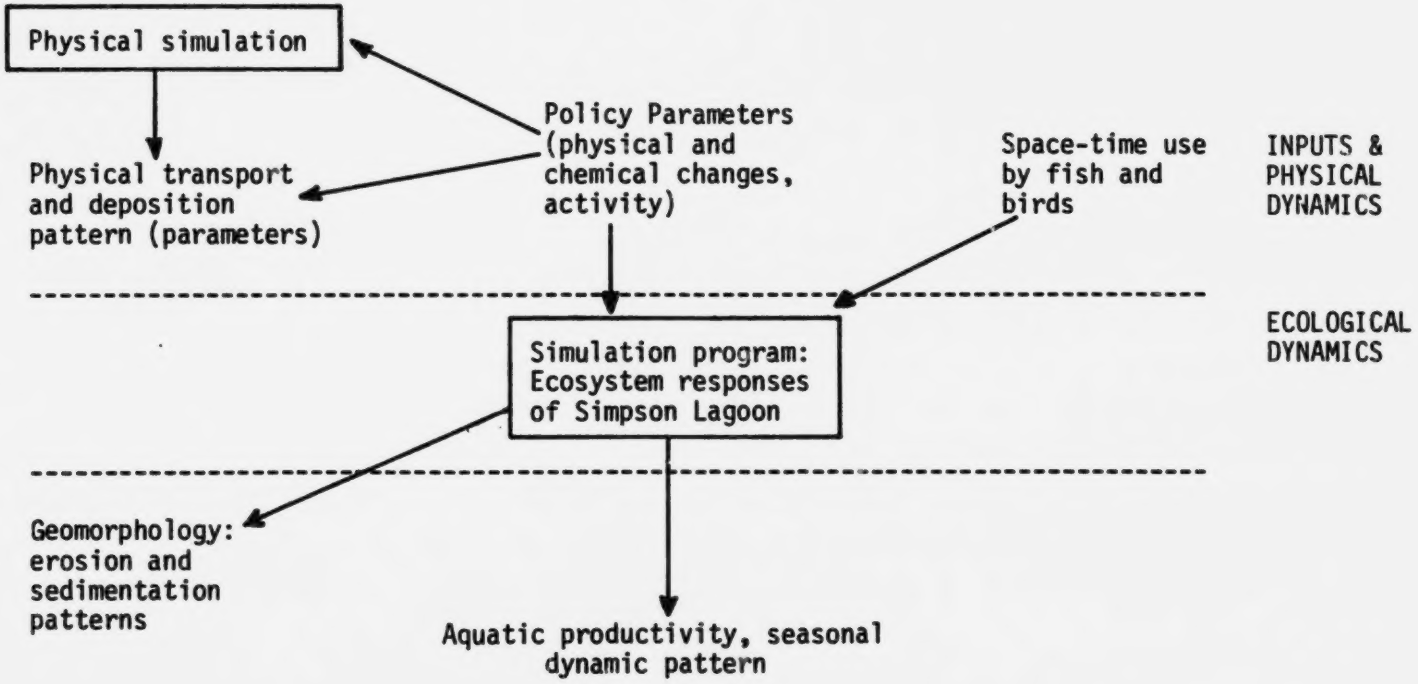
Physical simulation
Policy Parameters (physical and chemical changes, activity)
Physical transport and deposition pattern (parameters)
Space-time use by fish and birds
INPUTS & PHYSICAL DYNAMICS
ECOLOGICAL DYNAMICS
Simulation program: Ecosystem responses of Simpson Lagoon
Geomorphology: erosion and sedimentation patterns
Aquatic productivity, seasonal dynamic pattern

Figure 3. Structure of model inputs and internal computations.

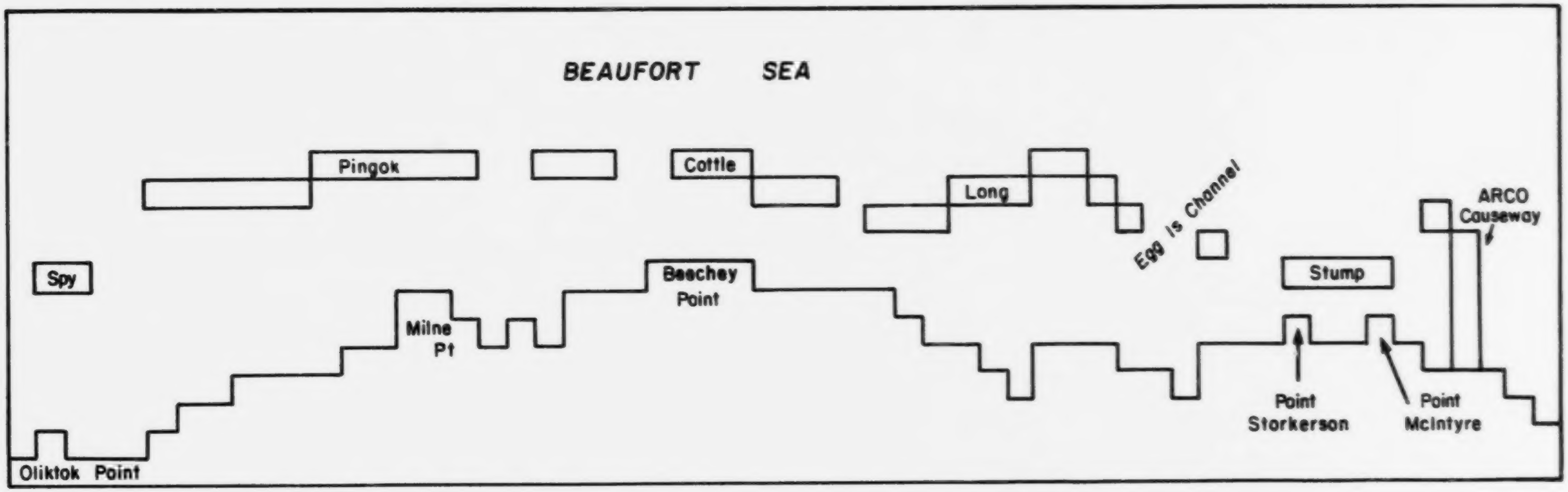
BEAUFORT SEA
Pingok
Cottle
Long
Egg Is Channel
ARCO Causeway
Spy
Beechey Point
Stump
Milne Pt
Point Storkerson
Point McIntyre
Oliktok Point

Figure 4. Grid system map used in physical current simulation model.

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assumed to be constant at 6 feet. Consequently, the predictions are very approximate. The model is run with a set of predetermined, steady winds using radiation conditions applied at the boundary, of the form:

> outward current times depth = wave celerity times surface elevation above mean sea level

The boundary conditions are applicable only for releasing transient wave energy and cannot be used to obtain steady state currents. For reasons of economy, computations were carried out for six hours only starting from rest conditions (0 currents, sea surface at mean sea level). As a result, the estimates of current and exchange rate in the lagoon are likely conservative.

The physical factors initialization subroutine of the lagoon ecosystem model does not actually simulate any dynamics. Instead, it assigns values to variables used in other places in the model according to a pre-established sequence of weather conditions created from time series data on wind velocities for the Simpson Lagoon area. This time series data on wind velocities was used to create a seasonal wind pattern for the area. The sequence involved three wind directions (east-northeast, northwest, and west-southwest) and four different speeds for each direction. The physical oceanography model was run for each of these twelve wind cases, generating water current patterns from which corresponding values for the following variables were calculated by the physical factors initialization subroutine.

(a) daily volume exchange of the lagoon
(b) mean current speed in center of lagoon
(c) mean shoreline currents
(d) length of exposed shoreline
(e) length of protected shoreline
(f) wave period

These variables, along with a time series of freshwater runoff and ice cover and the sequence of wind velocities, formed the main set of driving variables for the rest of the ecosystem model. For each simulated day of the model, the physical submodel assigned values to these variables corresponding to the sequence of wind velocities.

Geology Submodel. This submodel deals with the inputs of organic and inorganic material into the lagoon from the terrestrial system. The model considers terrestrial materials from two sources. The first source arises from erosion of the shoreline tundra material. It is assumed that wave action and currents create slumping of the tundra onto the beach. The slumped material is then washed into the lagoon as a consequence of both wave action and long-shore currents. When this material is moved away, an overhang is created and subsequent slumping occurs. The number of slumps is assumed to increase with increased wave action.

For the purpose of the geology submodel, the shoreline is divided into four categories: low (1.5 m) and high (2.5 m), both exposed and sheltered. The volume of material slumped is a product of the height of the tundra in the shoreline type, the average width of a slump for that shoreline type (depending on exposed versus sheltered), and the length of shoreline of that type. The material, once on the beach, is moved into the water-column and subsequently the lagoon by two processes. The material is suspended due to wave action. Once suspended, it is carried away by long-shore currents. The composition of a material is assumed to be 30% organic in the high-profile shoreline and 20% in the low-profile shoreline.

The other source of terrestrial material that enters the lagoon comes from the freshwater system. The vast majority of this material is moved prior to break-up but after the freshwater flow begins. In the model, this material is assumed to sit on top of the ice and then enter the lagoon during the first week of break-up. This material is assumed to be 75% organic by volume.

There are three major indicators that result from the calculations in the geology model:

(a) the total organic material added to the lagoon;
(b) the total inorganic material added to the lagoon; and
(c) the cumulative distance of shoreline eroded.

Aquatic Biology Submodel. This submodel predicts the productivity of the lagoon system for fish and birds in relation to physical and chemical conditions. To accomplish this task, the whole aquatic food chain from nutrients through primary productivity to grazers and fish was examined. The representation of the lagoon food chain is based on three types of primary productivity (ice algae, phytoplankton, benthic algae) and on detritus inputs from the terrestrial system (further subdivided into freshwater runoff and shoreline erosion). The primary production and detritus is processed by zooplankton and benthos to generate food for birds and fish. Ice algae is measured simply in terms of standing crop available for grazers and detritus formation at the time of ice break-up. The model does not simulate winter and spring growth dynamics of ice algae but assumes that a given standing crop is available at ice break-up each year, at least in the absence of direct poisoning due to oil or other pollutants.

Nitrogen, phytoplankton, zooplankton dynamics were represented, as in most modeling studies, as a biomass compartment flow system with movement rates of material between compartments depending on "donor" and "receiver" biomass pool available. The FORTRAN code provided in Appendix 1 includes detailed comments on the aquatic system dynamics.

Terrestrial Biology Submodel. The initial workshop considered both birds and mammals in the terrestrial biology submodel. The birds considered were oldsquaws, eiders, shorebirds, brant, loons, and terns. Each group of birds was divided into breeding and non-breeding components for determination of the proportion feeding in each habitat. The amounts of food organisms eaten by each species or group of birds were calculated in 'oldsquaw equivalents' (i.e., the food consumption of individuals of each species or group was expressed in terms of the proportion of estimated oldsquaw consumption).

The mammals considered in the first model were foxes and lemmings. Fox numbers were dependent on amount of fox food (lemmings, birds, and human refuse).

Later versions of the model progressively de-emphasized the diversity of bird species and the mammals, resulting in a model which now considers only the effects of oldsquaw feeding on benthos biomass.

Transfers Between Submodels. Prior to submodel preparation, the exchanges of information between submodels were defined by the workshop participants. The resulting matrix from the first workshop is shown in Table 2, and the matrix for the most recent model is shown in Table 3. The differences represent changes in the focus of the modeling effort during the project.

Table 2. Quantitative information transfers between modeling teams and internal team concerns necessary to generate transfers at first workshop.

"Generated By" Submodel	"Received By" Submodel			
	Physical Oceanography	Aquatic Ecosystems	Geophysical Processes	Birds and Mammals
Physical oceanography and sedimentation	(Internal) - currents - silt and detritus settling rates - wind and waves - oil movement	1. Volume exchange rates (longshore and offshore, proportion/10 days 2. Turbidity, ppm 3. Detritus delivered to sediment gC/10 days 4. Ice thickness, m 5. Oil presence or absence	1. Freshwater discharge m^3/sec, from local sources 2. Lagoon current velocity map 3. Mean wave period (m)	1. Number of storms/10 days 2. Turbidity, ppm 3. Ice thickness, m 4. Oil, present or absent
Aquatic ecosystem dynamics		(Internal) - nitrogen dynamics - primary production - zooplankton, benthos - fish populations		1. Zooplankton density, gC/m by aquatic habitat 2. Benthos density, gC/m^2 by habitat 3. Small fish (larvae and juveniles) density, No/m^2 by habitat
Geophysical processes	1. Tons silt flushed into lakes and estuaries, per 10 days 2. Tons of detrital C added to waters/10 days	1. Sediment composition (1% gravel, % sand, % clay) 2. Habitat sizes: km^2 of water types, km of shoreline	(Internal) - land forms - erosion rates	1. Habitat types: km^2 land area, km shoreline 2. Shoreline mean particle size (mm)
Terrestrial biology: birds and mammals		1. Nitrogen inputs (g) per 10 days from land sources 2. Consumptions of zooplankton, benthos, fish/m^2 /10 days	1. Detritus added (tons C/10 days) by small mammal clipping	(Internal) - densities by habitat - migration patterns - vegetation responses to grazing, disturbance

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Table 3. Quantitative information transfers between modeling teams and internal team concerns necessary to generate transfers at last workshop.

	"Received By" Submodel			
"Generated By" Submodel	Physical Oceanography	Aquatic Ecosystems	Geophysical Processes	Birds and Mammals
Physical oceanography and sedimentation	(Internal) - currents - silt and detritus settling rates - wind and waves - oil movement	1. Volume exchange rates (longshore and offshore, proportion/10 days 2. Turbidity, ppm 3. Detritus delivered to sediment gC/10 days 4. Ice thickness, m 5. Oil presence or absence	1. Freshwater discharge m^3/sec, from local sources 2. Lagoon current velocity map 3. Mean wave period (m)	1. Number of storms/10 days 2. Oil, present or absent
Aquatic ecosystem dynamics		(Internal) - nitrogen dynamics - primary production - zooplankton, benthos - fish populations - invertebrate consumption by fish		1. Zooplankton density, gC/m by aquatic habitat 2. Benthos density, gC/m^2 by habitat
Geophysical processes	1. Tons silt flushed into lakes and estuaries, per 10 days 2. Tons of detrital C added to waters/10 days	1. Habitat sizes: km^2 of water types, km of shoreline	(Internal) - erosion rates	
Terrestrial biology: birds and mammals		1. Consumption of zooplankton, benthos per m^2/10 days		(Internal) - densities by habitat each week

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APPENDIX 1. The Barrier Island-Lagoon Computer Simulation Model (as of 1 February 1980).

Following is a copy of the FORTRAN code of the latest version of the ecological portion of the Barrier Island-Lagoon Computer Simulation Model. This model, as described earlier in this report, was developed for use as a heuristic tool for modeling workshops and has changed substantially at intervals since the first workshop in December 1976. It is primarily of use for investigation of trophic relationships in the Barrier Island-Lagoon system. A major restructuring of the model will be required if it is to be used for investigation of many of the other site-specific and regional issues that have been highlighted by this project.

The model is written for execution by SIMCON, an interactive simulation control software package (Hilborn 1973). SIMCON provides a great deal of flexibility in input of data and output of model predictions, so the reader will note that the model code has no I/O capability.

The model code represents the instructions necessary for the execution of one time step (1 day, 1/100 of a year). Comments in the program will explain the details of the calculations involved; however, two unusual aspects of the program that are related to SIMCON should be mentioned:

1. The subroutines UINIT and UMODEL are SIMCON conventions; UINIT passes required information to SIMCON, and UMODEL is the actual model that is executed each time step.
2. The common block is large and is included in all subroutines (except UINIT) in order to fit into the I/O system in SIMCON. SIMCON simply 'dumps' the common block into a disc file each time step; all variables for all time steps are thereby available for printed or plotted output after the simulation is complete.

This model uses the output (waterflow, wave period, current velocity) of the oceanographic computer simulation model provided by J.C.H. Mungall (Research Unit 531).

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SUBROUTINE UINIT

```
      SUBROUTINE UINIT
C  THE SUBROUTINE UINIT TELLS SIMCON THE NAMES OF THE DATA FILE AND THE
C  FILE CONTAINING THE COMMON BLOCK.
      CALL DFAULT('1=BBEAU.D ')
      CALL CMREAD('BBEAU.C ')
      RETURN
      END
```

SUBROUTINE UMODEL

```
      SUBROUTINE UMODEL(IT)
C
C  THE SUBROUTINE UMODEL IS THE ACTUAL MODEL THAT SIMCON EXECUTES EACH
C  TIME PERIOD.
C
C
COMMON ASC(13),FISHE(13),INAB(6),CALDAT(3),GBAMPC
COMMON ZOOPL,BENTH(14),ALGIC(14),PHYTO,BENALG(14),H(14)
COMMON ZOOIN(2),PHYIN(2),AICE(14),DEPOL(14),DETIN(14)
COMMON NSTP,DELTP,GPHN,CNIT,CNIN,GPATE,SINKB,VEG(13)
COMMON FNOUT(10),BZOO,BPHYT,BBEN,OCNIT,FISHL(14)
COMMON ZOOCB(10),FISHBB,ANAD(10,5),CHAB(14),FLARV(14),OEX
COMMON BENIN(14),OEXIN,FIFB,BENCB,BIRDS(6),PRES(6,10),ZOOE
COMMON AREA(14),TVOLW,DETAL,TAREA,OIL,BENTE(13),VEGE(13)
COMMON TNIG(6),BREED(6),INIG(6,10),SHORE,IDAY,DICE(14),DADD(14)
COMMON CUPE,WAVE,GSHEFF(14),EMAX,ESENS,POWWAT,IYEAR,IWEEK
COMMON GVOL(14),GLOST(14),GO(14),GI(14),GORG(14),GINOR(14)
COMMON NAREAS,J,I,GTHETA,GSPEED,GSLUMP,GSLOSL(3),GSLOMA(3)
COMMON GA,GB,GC(4),GD(4),GPROD,GPORG(13),GWTORG,GWTIN,GAMMA
COMMON GVCLPS,GWEROD,GSDRCI,GCW,GINW,TORG,TINO,Q
COMMON GININ,GINEX(12),GWIDSL(13),GWTINO,IGMOVE,GDISTC
COMMON IW,INTS(10,10),OUTFLO(12),EXPSHO(12),PROSHO(12)
COMMON Q1,Q11,Q2,Q22,Q3,Q33,Q4,Q44,Q5,Q55,POUT,EOUT,COUT
COMMON CVK,SP(2),CV(2),SUSP,DPPOS,SRATE,DRATE,CINFW,SLOSS
COMMON CNBAF,DETR,DPTOUT(15),DINPW,DETBC,SPHYT,SGAIN
COMMON CCLONB(10),CCNBAT,SINKBI,CHAPS,CVEL,DEXTER(12)
COMMON DETWN,PREMIN,BREM,EXFBI,EXFN,XICE(13,10),TURB(13)
COMMON ISTP,GPORGP,OCN(15),WSURV,SFISH(14),SFISHI(10,14)
COMMON GBHAP,FISSBR,QK,QS,GTOPG,GTING,GHIGH(13),GTIN,GTOR
COMMON BEKAL(14),FISHEF,BAPR,ENUSE,BATPH,DATPH,GBUG1
COMMON BCCNF(14),GBUG2,BFOOD(14),ECHAR(14),ESFISH(14)
COMMON FOSABD,PNUP,BENIN,GBEN(14),PHUDGE,DUMMY,CVPLI(12)
COMMON HUNGRY(2,14),A,B,BTIMES,EATEN,CURENT(12),WAVEE(12)
C
C
      IYEAR = (IT-1)/100 + 1
      ITT = IT - (IYEAR-1)*100
      IWEEK = (ITT-1)/10 + 1
      IDAY = MOD(ITT-1,10) + 1
C
C   CALL THE PHYSICAL FACTORS INITIALIZATION SUBROUTINE.
C
      CALL PHYS
C
C SET UP EXTERNAL INORGANIC AND ORGANIC INPUTS
C
      DETOUT(IWEEK) = DEXTER(IW)
      OCNIT =  OCN(IWEEK)
      GININ = GINEX(IW)
C
C   CALL THE GEOLOGY SUBROUTINE.
C
      CALL GEO
C
C   CALL THE AQUATIC BIOLOGY SUBROUTINE.
C
```

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APPENDIX 1 (cont'd)

SUBROUTINE UMODEL (cont'd)

```
        CALL ACU
C
C   CALL THE BIRD TROPHICS SUBROUTINE.
C
        CALL BIRDY
        RETURN
        END
```

SUBROUTINE BIRDY

```
        SUBROUTINE BIRDY
C
C   THIS IS THE SUBROUTINE THAT DOES ALL THE CALCULATIONS INVOLVING BIRD
C   FEEDING.
C   NOTE THAT ALL BIRDS DO IN THIS MODEL IS EAT.
C
C
C
COMMON ASC(13),FISHE(13),IHAB(6),CALDAY(3),GRASPC
COMMON ZOOPL,BENTH(14),ALGIC(14),PHYTO,BPNALG(14),H(14)
COMMON ZOOIN(2),PHYIN(2),AICE(14),DEPOL(14),DETIN(14)
COMMON NSTP,DELTP,GPHK,CRIT,CMIN,GEATE,SINKR,VEG(13)
COMMON FHOUT(10),RZOO,RPHYT,RBEN,OCNIT,FISHL(14)
COMMON ZOOCN(10),FISHBR,ANAD(10,5),CHAR(14),PLARV(14),OEI
COMMON BENIN(14),OEXIN,FIFR,BENCR,BIRDS(6),PRES(6,10),ZOOE
COMMON AREA(14),TVOLW,DETAL,TAREA,OIL,BENTE(13),VEGE(13)
COMMON YBIG(6),BREED(6),XBIG(6,10),SHORE,IDAY,DICE(14),DADD(14)
COMMON CUBE,WAVE,GSHEFF(14),EMAX,ESENS,PONWAT,IYEAR,IWEEK
COMMON GVOL(14),GLOST(14),GO(14),GI(14),GORG(14),GINOR(14)
COMMON NAREAS,J,I,GTHETA,GSPEED,GSLUSP,GSLUSL(3),GSLUMA(3)
COMMON GA,GB,GC(4),GD(4),GERCD,GPORG(13),GWTORG,GWTIN,GAREA
COMMON GVCLPS,GWEBOD,GSUMDI,GCW,GINW,TORG,TINO,Q
COMMON GININ,GIKEX(12),GWIDSL(13),GWTINO,IGMOVE,GDISTC
COMMON IN,INTH(10,10),CUTFLO(12),EXPSHO(12),PROSHO(12)
COMMON Q1,Q11,Q2,Q22,Q3,Q33,Q4,Q44,Q5,Q55,POUT,ZOUT,COUT
COMMON CVK,SR(2),CV(2),SUSP,DEPOS,SRATE,DRATE,CINFW,SLOSS
COMMON CNHAF,DETR,DETOUT(15),DINFW,DETRC,SPHYT,SGAIN
COMMON COLONB(10),GCNRAT,SINKMX,CHAPS,CVEL,DEXTER(12)
COMMON DETWN,PREMIN,BRES,EXFMX,EXFN,XICE(13,10),TURB(13)
COMMON XSTP,GPORGP,OCN(15),WSURV,SFISH(14),SFISHI(10,14)
COMMON GNHAF,FISSBR,QK,QS,GTORG,GTING,GHIGH(13),GTIN,GTOR
COMMON BENAL(14),FISHEP,BAPH,ENUSE,BATPH,DATPH,GBUG1
COMMON BCONF(14),GBUG2,BFOOD(14),ECHAR(14).ESFISH(14)
COMMON FUSABD,PKOP,REMIN,GBEN(14),PHODGE,DUMMY,CVELI(12)
COMMON HUNGRY(2,14),A,B,BTIMES,EATEN,CURENT(12),WAVEE(12)
C
C
C
C   BIRD FEEDING IS CALCULATED ON THE FIRST DAY OF EACH 10 DAY 'WEEK'.
C
        IF (IDAY .NE. 1) GO TO 99
C
C       INITIALIZE THE AMOUNT EATEN
C
        DO 20 I = 1, 13
        BENTE(I) = 0.
        FISHE(I) = 0.
        VEGE(I) = 0.
     20 CONTINUE
C
C
C   PUT IN THE NUMBER OF BIRDS THERE
C
        BIRDS(1) = PRES(1,IWEEK)
C
C   THIS SECTION FOR OLDSQUAWS
```

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SUBROUTINE BIRDY (cont'd)

```
C     CALC. GRAMS CARBON EATEN PER BIRD
C
      EATEN=A*BENTH(2)/(B+BENTH(2))
C
C     CALC. TOTAL GRAMS EATEN/ SQ. METER DEEP WATER
C
      BENTE(2)=EATEN*BIRDS(1)/(AREA(2)*1.E6)
      IF(BENTE(2).GT..9*BENTH(2)) BENTE(2)=.9*BENTH(2)
C
   11 CONTINUE
   10 CONTINUE
C
   99 CONTINUE
      RETURN
      END
```

FUNCTION SLP

```
      FUNCTION SLP(X,XX,YY,N)
C
C    THE FUNCTION SLP IS A LINEAR INTERPOLATER.  GIVEN ARRAYS XX AND YY AND X,
C    IT RETURNS Y, INTERPOLATED BETWEEN TWO NEAREST POINTS. N=NUMBER OF POINTS.
C
      DIMENSION XX(20), YY(20)
      SLP = YY(1)
      IF (X .LT. XX(1)) GO TO 99
      N = N - 1
      DO 10 I = 1, N
      IF (X .GT. XX(I+1)) GO TO 10
      SLP = YY(I)+(YY(I+1)-YY(I))/(XX(I+1)-XX(I))* (X-XX(I))
      GO TO 99
   10 CONTINUE
      SLP = YY(N)
   99 RETURN
      END
```

SUBROUTINE AQU

```
      SUBROUTINE AQU
C
C     NOTE THAT OIL IS USED THROUGHOUT THIS SUBROUTINE TO
C     REDUCE FEEDING AND RESUSPENSION RATES
C
C
COMMON  ASC(13),FISHE(13),IHAB(6),CALDAY(3),GRAMPC
COMMON  ZOOPL,BENTH(14),ALGIC(14),PHYTO,BENALG(14),H(14)
COMMON  ZOOIN(2),PHYIN(2),AICE(14),DEPOL(14),DETIN(14)
COMMON  WSTP,DELTP,GPHN,CNIT,CNIN,GRATE,SINKR,VEG(13)
COMMON  PHOUT(10),RZOO,RPHYT,REEM,OCNIT,FISHL(14)
COMMON  ZOOCN(10),FISHBR,ANAD(10,5),CHAR(14),PLARV(14),OEX
COMMON  BENIN(14),OEXIN,PIFR,BENCR,BIRDS(6),PRES(6,10),ZOOE
COMMON  AREA(14),TVOLW,DETAL,TAREA,OIL,BENTE(13),VEGE(13)
COMMON  YMIG(6),BREED(6),XMIG(6,10),SHORE,IDAY,DICE(14),DADD(14)
COMMON  CORE,WAVE,GSHEFF(14),EMAX,ESENS,PONWAT,IYEAR,IWEEK
COMMON  GVOL(14),GLOST(14),GO(14),GI(14),GORG(14),GINOR(14)
COMMON  NAREAS,J,I,GTHETA,GSPEED,GSLUMP,GSLDSL(3),GSLUMA(3)
COMMON  GA,GB,GC(4),GD(4),GEROD,GPORG(13),GWTORG,GWTIN,GAREA
COMMON  GVOLPS,GWEROD,GSUMDI,GCW,GINW,TORG,TINO,Q
COMMON  GININ,GINPX(12),GWIDSL(13),GWTINO,IGMOVE,GDISTC
COMMON  IW,IWTH(10,10),OUTPLO(12),EXPSHO(12),PROSHO(12)
COMMON  Q1,Q11,Q2,Q22,Q3,Q33,Q4,Q44,Q5,Q55,POUT,ZOUT,COUT
COMMON  CVK,SR(2),CV(2),SUSP,DEPOS,SRATE,DRATE,CINFW,SLOSS
COMMON  CNHAP,CETR,DETOUT(15),DINFW,DETRC,SPHYT,SGAIN
COMMON  CCLONB(10),GCNRAT,SINKRI,CHAPS,CVPL,DEXTER(12)
```

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SUBROUTINE AQU (cont'd)

```
      COMMON DETWN,PREMIN,ABPM,EXPMX,EXPM,XICE(13,10),TURB(13)
      COMMON ISTP,GPORGP,OCN(15),WSURV,SFISH(14),SFISHI(10,14)
      COMMON GRHAF,FISSBR,QK,QS,GTCEG,GTING,GHIGH(13),GTIN,GTOB
      COMMON BENAL(14),FISHEP,BAPH,ENUSE,BATPH,DATPH,GBUG1
      COMMON BCONP(14),GBUG2,BFOOD(14),ECHAR(14),ESFISH(14)
      COMMON PUSABD,PNUP,BEMIN,GBEN(14),PHUDGE,DUMMY,CVELI(12)
      COMMON HUNGRY(2,14),A,B,ETIMES,EATEN,CURENT(12),WAVES(12)
C
C
         BEPOL=0.
         BNUSE=0.
         BATPH=0.
         DATPH=0.
         IF(IDAY.NE.1)GO TO 209
C
C    IF IT IS THE FIRST DAY OF THE FIRST PERIOD, ACCUMULATE ALL THE BENTHOS
C    IN THE DEEP LAGOON AND APPLY A WINTER SURVIVAL RATE.
C
         IF(IWEEK.NE.1)BENTH(2)=BENTH(2)+(BENTH(3)+BENTH(4)+BENTH(5))*WSURV
    209 CONTINUE
C
C    LOOP OVER LAGOON HABITATS
C
         DO 201 IH=2,5
C
C    SET THIS WEEK'S FISH POPULATIONS TO THE DATA.  SFISH IS SMALL FISH (I.E.
C    ARCTIC COD).
C
         CHAR(IH)=ANAD(IWEEK,IH)
         SFISH(IH)=SFISHI(IWEEK,IH)
C
C    IF THERE IS ICE THERE ARE NO FISH.
C
         IF(DICE(IH).GT.0.)CHAR(IH)=0.
C
C    SET FISH LARVAE.
C
         FISHL(IH)=FLARV(IWEEK)
         IF(DICE(IH).GT.0.)FISHL(IH)=0.
         IF(IDAY.NE.1)GO TO 202
C    SET INITIAL VALUES IF THIS IS PERIOD 1
         IF(IWEEK.NE.1)GO TO 202
C
C    INITIAL VALUES FOR:
C     FISCON--ZOOPLANKTON CONSUMED BY FISH
C     ZOOPL--ZOOPLANKTON IN THE WATER COLUMN
C     DETR--DETRITUS IN THE WATER COLUMN
C     CHAR--ARCTIC CHAR
C     FISHL--FISH LARVAE
C     PHYTO--PHYTOPLANKTON IN THE WATER COLUMN
C     ALGIC--ICE ALGAE
C
         FISCON=0.
         ZOOPL=ZOOIN(2)
         DETR=DETWN
         CHAR(IH)=0.
         FISHL(IH)=0.
         PHYTO=PHYIN(2)
         ALGIC(IH)=AICE(IH)*(1.-OIL)
         IF(IH.NE.2)BENTH(IH)=0.
C
C    THE DETRITUS IN THE DEEP LAGOON HABITAT IS INCREASED BY BOUNDARY
C    INPUTS AND REDUCED BY OVERWINTER GRAZING BY BENTHOS.  IT IS
C    ASSUMED THAT THE BENTHOS EAT 2 TIMES THEIR WEIGHT OVER THE WINTER.
C
         IF(IH.EQ.2)DEPOL(IH)=DEPOL(IH)+DETIN(IH)-2.*BENTH(2)
         IF(DEPOL(IH).LT.0.)DEPOL(IH)=0.
         IF(IH.NE.2)DEPOL(IH)=.01
C
C    SET INITIAL VALUES FOR NITROGEN CONCENTRATIONS
C
         CNIT=CNIN
         BENAL(IH)=0.
    202 CONTINUE
C
C    PUT ICE ALGAE INTO DETRITUS AFTER THE FIRST PERIOD.
C
```

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SUBROUTINE AQU (cont'd)

```
      IF(IWEEK.EQ.1) GO TO 203
      BENAL(IN)=BENAL(IN)+ALGIC(IN)
      ALGIC(IN)=0.
  203 CONTINUE
C
C   CALCULATE WATER TURNOVER AND NUTRIENT INPUT CONC
C   SOLVE DIFFERENTIAL EQUATION FOR PHYTOPLANKTON, ZOOPLANKTON, AND
C   NITROGEN CONCENTRATIONS FOR DEEP LAGOON HABITAT IF THE ICE IS GONE.
C
      DETAL=0.
      BAPH=0.
      IF(DICE(IN).GT.0.)GO TO 205
      IF(IN.NE.2)GO TO 205
      IF(OIL.GT.1.E-6)OIL=OIL*EXP(-OEX)
C
C   SINKING RATE IS AN EXPONENTIALLY DECLINING FUNCTION OF THE CURRENT VELOCITY.
C
      SINKR=SINKEX*EXP(-.6943*CVEL/CHAFS)
C
C   CALCULATE THE NUMBER OF ITERATIONS AND THE TIME STEP FOR THE SOLUTION TO
C   ENSURE NUMERICAL STABILITY.  THE TIME STEP IS A FUNCTION OF THE WATER MASS
C   EXCHANGE RATE OF THE LAGOON (OEX).
C
      NSTP=ISTP*OEX
      IF(NSTP.LT.3)NSTP=3
      X=NSTP
      DELTP=1./X
      DO 204 INS=1,NSTP
C
C   PHYTOPLANKTON GROWTH IS A FUNCTION OF PHYTOPLANKTON DENSITY AND NITROGEN
C   CONCENTRATION.
C
      PNUP=GPHN*PHYTO*CNIT/(CNHAF+CNIT)*(1.-OIL)
C
C   GRAZING IS A FUNCTION OF BOTH PHYTOPLANKTON AND ZOOPLANKTON DENSITIES.
C
      GRAZ=GRATE*PHYTO*ZOOPL/(GRHAF+PHYTO)*(1.-OIL)
C
C   NET CHANGE IN PHYTOPLANKTON DENSITY IS A FUNCTION OF:
C    PNUP--GROWTH
C    GRAZ--GRAZING
C    RPHYT--RESPIRATION
C    SPHYT--SINKING(INDEPENDENT OF CURRENT SPEED)
C    OEX--WATER EXCHANGE (EMIGRATION)
C    PHOUT--WATER EXCHANGE (IMMIGRATION)
C
      DPHYT=PNUP-GRAZ-(RPHYT+SINKR+OEX)*PHYTO+OEX*PHOUT(IWEEK)
C
C   NET CHANGE IN NITROGEN CONCENTRATION IS A FUNCTION OF:
C    PHYTOPLANKTON GROWTH
C    ZOOPLANKTON RESPIRATION
C    PHYTOPLANKTON RESPIRATION
C    BENTHOS RESPIRATION
C    EXCHANGE IN AND OUT OF THE LAGOON
C    FRESHWATER INPUTS
C
      DNIT=-.1*PNUP+.1*(RZOO*ZOOPL+RPHYT*PHYTO+RBEN*BENTH(2))
     1-OEX*CNIT+OEX*OCNIT+.1*FUSAED*(.5*DEPOL(2)+DETR)
C
C   CONSUMPTION OF ZOOPLANKTON BY FISH IS A FUNCTION OF ZOOPLANKTON AND FISH
C   LARVAE DENSITIES.
C
      FISCON=FIFR*ZOOPL*FISHL(IN)
C
C   NET CHANGE IN ZOOPLANKTON DENSITIES IS A FUNCTION OF:
C    PHYTOPLANKTON GRAZING
C    FISH CONSUMPTION
C    RESPIRATION
C    EXCHANGE (IMMIGRATION AND EMIGRATION)
C
      DZOO=.5*GRAZ-FISCON-RZOO*ZOOPL-OEX*(ZOOPL-ZOOCN(IWEEK))
C
C   NET CHANGE IN THE DETRITUS IN THE WATER COLUMN IS DEPENDENT ON:
C    ZOOPLANKTON GRAZING AND EXCRETION
C    PHYTOPLANKTON SINKING
C    FRESHWATER DETRITUS
C    EXCHANGE IN THE WATER COLUMN
C    SINKING OF DETRITUS FROM THE WATER COLUMN
C
```

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APPENDIX 1 (cont'd)

SUBROUTINE AQU (cont'd)

```
      DETRC=.5*GRAZ+DINFW+OEX*(DETOUT(IWEEK)-DETR)
     1-SINKB*DETR-PUSABD*DETR
C
C   UPDATE DETRITUS, ZOOPLANKTON, NITROGEN AND DETRITUS POOL.
C
      DETR=DETR+DETRC*DELTP
      IF(DETR.LT.1.E-6)DETR=1.E-6
      ZOOPL=ZOOPL+DZOO*DELTP
      IF(ZOOPL.LT.1.E-6)ZOOPL=1.E-6
C
C   ACCUMULATE DETRITUS AND PHYTOPLANKTON SINKING TO THE BOTTOM
C
      DETAL=DETAL+SINKB*DETR*DELTP
      BAPH=BAPH+SINKB*PHYTO*DELTP
      PHYTO=PHYTO+DPHYT*DELTP
      IF(PHYTO.LT.1.E-6)PHYTO=1.E-6
      CNIT=CNIT+BNIT*DELTP
      IF(CNIT.LT.1.E-6)CNIT=1.E-6
  204 CONTINUE
  205 CONTINUE
C
C   DYNAMIC CHANGES IN BENTHOS
C   CALCULATE ONLY FOR LAGOON HABITATS
C
      IF(IH.LT.2.OR.IH.GT.5)GO TO 201
C
C   IF IT IS NOT WINTER ADD THE DETRITUS THAT HAS SUNK TO THE POOL AT THE
C   BOTTOM.
C
      IF(IWEEK.NE.1)DEPOL(IH)=DETAL+DEPOL(IH)
C
C   RESUSPENSION RATE OF BENTHIC ALGAE
C
      SRATE=SLP(CVEL,CV,SB,2)*(1.-OIL)
      IF(IH.EQ.2)SRATE=.5*SRATE
C
C   UPDATE BENTHIC ALGAE FOR SINKING AND RESUSPENSION
C
      BENAL(IH)=BENAL(IH)+BAPH-SRATE*BENAL(IH)
C
C   GROWTH IS A FUNCTION OF DENSITY, OIL, NITROGEN, AND RESPIRATION
C
      BGROW=GPHW*BENAL(IH)*(1.-OIL)*CNIT/(CNHAF+CNIT)
     1-RPHYT*BENAL(IH)
      IF(BGROW.GT.10.*CNIT)BGROW=10.*CNIT
C
C   CALCULATE NITROGEN USED BY BENTHIC ALGAE
C
      BNUSE=BNUSE+.1*BGROW*AREA(IH)*1.E6
      BENAL(IH)=BENAL(IH)+BGROW
C
C   SUSPENDED BENTHIC ALGAE BECOMES PHYTOPLANKTON
C
      BATPH=BATPH+SRATE*BENAL(IH)*AREA(IH)*1.E6
C
C   REDUCE DETRITUS POOL BY BACTERIAL ACTIVATION AND RESUSPENSION
C
      DEPOL(IH)=DEPOL(IH)-(PUSABD+SRATE)*DEPOL(IH)
C
C   ADD RESUSPENDED DETRITUS TO THE WATER COLUMN
C
      DATPH=DATPH+SRATE*DEPOL(IH)*AREA(IH)*1.E6
C
C   TOTAL FOOD FOR BENTHOS
C
      BFOOD(IH)=BENAL(IH)+PUSABD*DEPOL(IH)+1.E-4
C
C   BENTHOS CONSUME DETRITUS POOL
C
      CONB=BENCR*BENTH(IH)*(1.-OIL)
      IF(CONB.GT..95*BFOOD(IH))CONB=.95*BFOOD(IH)
C
C   GROWTH OF BENTHOS
C
      GBEN(IH)=CONB/(BENTH(IH)+1.E-10)-RBEN+.1
      BENAL(IH)=BENAL(IH)-CONB*BENAL(IH)/BFOOD(IH)
      DEPOL(IH)=DEPOL(IH)-CONB*PUSABD*DEPOL(IH)/BFOOD(IH)
```

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APPENDIX 1 (cont'd)

SUBROUTINE AQU (cont'd)

```
         IF(BENAL(IH).LT.1.E-6)BENAL(IH)=1.E-6
         IF(DEPOL(IH).LT.1.E-6)DEPOL(IH)=1.E-6
C
C    BENTHOS EATEN BY CHAR AND SMALL FISH
C
         ECHAR(IH)=FISHBR*BENTH(IH)/(FISHEF+BENTH(IH))*(1.-OIL)
         HUNGRY(1,IH) = ECHAR(IH) / FISHBR
         ESFISH(IH)=FISSBR*BENTH(IH)/(FISHEF+BENTH(IH))*(1.-OIL)
         HUNGRY(2,IH) = ESFISH(IH) / FISSBR
         BCONF(IH)=ECHAR(IH)*CHAR(IH)+ESFISH(IH)*SFISH(IH)
C
C    CHANGE IN BENTHOS IS A FUNCTION OF:
C     EATING DETRITUS
C     BEING EATEN BY FISH
C     BEING EATEN BY BIRDS
C     RESPIRATION
C     IMMIGRATION OR COLONIZATION
C
         BENTH(IH)=CONB-BCONF(IH)-BENTE(IH)-RBEN*BENTH(IH)
        1+COLONB(IWEEK)*CEX+BENTH(IH)-.2*OIL*BENTH(IH)
         IF(BENTH(IH).LT..0001)  BENTH(IH)=.0001
         EXRT=EMAX*BENTH(IH)/(1.+CONB/(BENTH(IH)+.0001)/ESENS)
         BENTH(IH)=BENTH(IH)-EXRT
         BMPOL=BMPOL+EXRT*AREA(IH)*1.E6
         IF(BENTH(IH).LT.1.E-6)BENTH(IH)=1.E-6
C
C    END OF LOOP OVER AQUATIC HABITATS
C
     201 CONTINUE
C
C    UPDATE DETRITUS AND PHYTOPLANKTON IN THE WATER COLUMN
C    FOR RESUSPENSION
C
         DETR=DETR+DATPH/TVOLW
         PHYTO=PHYTO+BATPH/TVOLW
C
C    UPDATE NITROGEN FOR USE BY BENTHIC ALGAE
C
         CNIT=CNIT-BNUSE/TVOLW
         IF(CNIT.LE.1.E-6)CNIT=1.E-6
C
C    EMIGRATION OF PHYTOPLANKTON ZOOPLANKTON AND NITROGEN
C
         POUT=PHOUT(IWEEK)
         ZOUT=ZOOCN(IWEEK)
         COUT=CCNIT
         RETURN
         END
```

SUBROUTINE GEO

```
         SUBROUTINE GEO
C
C
COMMON  ASC(13),FISHE(13),IHAB(6),CALDAT(3),GRAMPC
COMMON  ZOOPL,BENTH(14),ALGIC(14),PHYTO,BENALG(14),H(14)
COMMON  ZOOIN(2),PHYIN(2),AICE(14),DEPOL(14),DETIN(14)
COMMON  NSTP,DELTP,GPHN,CNIT,CNIN,GRATE,SINKR,VEG(13)
COMMON  PHOUT(10),RZOO,RPHYT,RBEN,OCNIT,FISHL(14)
COMMON  ZOOCN(10),FISHBR,ANAD(10,5),CHAR(14),FLARV(14),OEX
COMMON  BENIN(14),OEXIN,FIFR,BENCR,BIRDS(6),PRES(6,10),ZOOE
COMMON  AREA(14),TVOLW,DETAL,TAREA,OIL,BENTE(13),VEGE(13)
COMMON  YMIG(6),BREED(6),EMIG(6,10),SHORE,IDAY,DICE(14),DADD(14)
COMMON  CUBE,WAVE,GSHEFF(14),EMAX,ESENS,PONBAT,IYEAR,IWEEK
COMMON  GVOL(14),GLOST(14),GO(14),GI(14),GORG(14),GINOR(14)
COMMON  NAREAS,J,I,GTHETA,GSPEED,GSLUMP,GSLUSL(3),GSLUMA(3)
COMMON  GA,GP,GC(4),GD(4),GEROD,GPORG(13),GWTORG,GWTIN,GAREA
COMMON  GVOLPS,GWEROD,GSUMDI,GCW,GINW,TORG,TINO,Q
COMMON  GININ,GINEX(12),GWIDSL(13),GWTINO,IGROVE,GDISTC
COMMON  IW,IWTH(10,10),OUTFLO(12),EXPSHO(12),PROSHO(12)
COMMON  C1,C11,Q2,Q22,Q3,Q33,Q4,Q44,Q5,Q55,POUT,ZOUT,COUT
```

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APPENDIX 1 (cont'd)

SUBROUTINE GEO (cont'd)

```
      COMMON CVK,SR(2),CV(2),SUSP,DEPOS,SPATE,DRATE,CINFW,SLOSS
      COMMON CNHAF,DETR,DETCUT(15),DINFW,DETBC,SPHYT,SGAIN
      COMMON COLONB(10),GCNRAT,SINKMI,CHAPS,CVEL,DEXTER(12)
      COMMON DETWN,PREMIN,BREM,EXPMI,EXPH,XICE(13,10),TURB(13)
      COMMON ISTP,GPORGF,OCN(15),WSURV,SFISH(14),SFISHI(10,14)
      COMMON GFHAF,FISSBR,QK,QS,GTORG,GTING,GHIGH(13),GTIN,GTOR
      COMMON BENAL(14),FISHEF,BAPH,ENUSE,BATPH,DATPH,GBUG1
      COMMON ECOFF(14),GBUG2,BFOOD(14),FCHAB(14),ESFISH(14)
      COMMON PUSABD,PKUP,REMIN,GBEN(14),PHUDGE,DUMMY,CVELI(12)
      COMMON HUNGRY(2,14),A,B,BTIMES,EATEN,CURENT(12),WAVEE(12)
C
C
C   GEOMORPHOLOGICAL CALCULATIONS
C   SHORE EROSIION
C   LOOP OVER AREAS
C   GVOLPS IS IN SQ METERS
C
      DO 310  J=1,NAREAS
C
C   IF THERE IS ICE THERE IS NO EROSION
C
      IF(DICE(J).GT.0.01) GO TO 319
C
C   DO EROSION FOR SHORELINES ONLY
C
      IF(J.NE.6.AND.J.NE.7.AND.J.NE.12.AND.J.NE.13) GO TO 310
      GVOLPS = GWIDSL(J) * GHIGH(J)
C
C   CALC. # SLUMPS/10 DAY PERIOD
C
      GSLUMP = SLP(WAVE,GSLUSL,GSLUMA,3)
C
C   TOTAL VOLUME OF SLUMPED MATERIAL ON EXPOSED SHORE IN CUBIC METERS
C
      GVOL(J) = (1000.*AREA(J)*GSLUMP*GVOLPS) + GVOL(J)
C
C   CALC. AMT. LOST DUE TO WAVES
C
      GEROD=GVOL(J)*(GA*EXP(GB*WAVE))*SLP(CURE,GC,GD,4)
C
C   EROSION DUE TO CURRENTS
C
      GVOL(J) = GVOL(J) - GEROD
C
C   GLOST(J) IS IN CUBIC METERS
C
      GLOST(J)=GEROD
  316 CONTINUE
C
C   CALCULATE AMOUNT OF ORGANIC AND INORGANIC MATERIAL ERODED
C   TO PUT INTO ADJACENT AREAS.
C   CALC. CU M. MATERIAL TIMES WEIGHT IN G/CC TIMES 1 MILLION CC/CU. M.
C   TIMES .72% ORGANIC CARBON
C
      GC(J) =  GLOST(J) * GPORG(J)*GWTORG *1.E6
      GI(J) = GLOST(J) * (1.-GPORG(J)) * GWTINO *1.E6
  310 CONTINUE
C
C   CALC. EROSION FROM WATERSHED INTO POND
C   CALC. AMT. ORGANIC C AND INORG MATTER DEPOSITED INTO LAGOON
C   FROM WATERSHED
C   GET GRAMS CARBON DUMPED INTO WATERSHED
C   THIS IS WATER FLOW IN CU. M/DAY TIMES 1000 LITERS/CU. M TIMES 50 MG/L
C   TIMES 2.7% CARBON
C
      GCW=0.
      GINW=0.
      IF(IWEEK.EQ.2)GCW=GTOR/10.
      IF(IWEEK.EQ.2)GINW=GTIN/10.
      GCW=GCW*GBUG1
      GINW=GINW*GBUG1
C
C   PUT ERODED MATERIAL INTO ADJACENT LAGOON, MATERIAL IN GRAMS C
C   OR IN M/DAY/CU. M. OF LAGOON WATER
C   DINFW = GRAMS C/DAY/CU. M. WATER
C
```

APPENDIX 1 (cont'd)

SUBROUTINE GEO (cont'd)

```
      DINFW   =(GO(7) + GO(6)+GO(12)+GO(13))*GBUG2 + GCW
      GTORG=GTORG+DINFW
      DINFW=DINFW/TAREA
C
C   TINO = GRAMS INORGANIC MATTER/DAY/CU. M. WATER
C
      TINO =(GI(6)  + GI(7)+GI(12)+GI(13)+GINW)
      GTING=GTING+TINO
      TINO=TINO/TVOLW + GININ
      GO TO 371
  319 CONTINUE
      DO 370 JJ=1,NAREAS
      DINFW = 0.0
      TINO = 0.0
      GSLUMP = 0.0
  370 CONTINUE
  371 CONTINUE
      RETURN
      END
```

SUBROUTINE PHYS

```
      SUBROUTINE PHYS
C
C   THIS IS THE PHYSICAL FACTORS INITIALIZATION SUBROUTINE.  IT MAKES
C   CALCULATICNS BASED ON INPUT FROM THE PHYSICAL OCEANOGRAPHY MODEL.
C
C
C
COMMON ASC(13),FISHE(13),IHAB(6),CALDAY(3),GRAMPC
COMMON ZOOPL,BENTH(14),ALGIC(14),PHYTO,BENALG(14),H(14)
COMMON ZOOIN(2),PHYIN(2),AICE(14),DEPOL(14),DETIN(14)
COMMON NSTP,DELTP,GPHW,CNIT,CNIN,GRATE,SINKR,VEG(13)
COMMON FROUT(10),RZOO,RPHYT,RBEN,OCNIT,FISHL(14)
COMMON ZOOCN(10),FISHBR,ANAD(10,5),CHAR(14),PLARV(14),OEX
COMMON BENIN(14),OEXIN,FIFR,BENCR,BIRDS(6),PRES(6,10),ZOOE
COMMON AREA(14),TVOLW,DETAL,TAREA,OIL,BENTE(13),VEGE(13)
COMMON YMIG(6),BREED(6),XMIG(6,10),SHORE,IDAY,DICE(14),DADD(14)
COMMON CURE,WAVE,GSHEFF(14),EMAX,ESENS,PONWAT,IYEAR,IWEEK
COMMON GVCL(14),GLOST(14),GO(14),GI(14),GORG(14),GINOR(14)
COMMON NAREAS,J,I,GTHETA,GSPEED,GSLUMP,GSLUSL(3),GSLUMA(3)
COMMON GA,GB,GC(4),GD(4),GEROD,GPORG(13),GWTORG,GWTIN,GAREA
COMMON GVOLPS,GWEROD,GSUMDI,GCW,GINW,TORG,TINO,Q
COMMON GININ,GINEX(12),GWIDSL(13),GWTINO,IGMOVE,GDISTC
COMMON IW,IWTH(10,10),OUTFLO(12),EXPSHO(12),PROSHO(12)
COMMON Q1,Q11,Q2,Q22,Q3,Q33,Q4,Q44,Q5,Q55,POUT,ZOUT,COUT
COMMON CVK,SR(2),CV(2),SUSP,DEPOS,SRATE,CRATE,CINFW,SLOSS
COMMON CNRAF,DETR,DETOUT(15),DINFW,DETRC,SPHYT,SGAIN
COMMON CCLOKB(10),GCNRAT,SINKMX,CHAPS,CVEL,DEXTER(12)
COMMON DETWN,PREMIN,BREM,EXPMX,EXPH,XICE(13,10),TURB(13)
COMMON ISTP,GPORGP,OCN(15),WSURV,SPISH(14),SPISHI(10,14)
COMMON GRRAF,FISSBR,QK,QS,GTORG,GTING,GHIGH(13),GTIN,GTOR
COMMON BENAL(14),FISHEP,BAPH,BNUSE,BATPH,DATPH,GBUG1
COMMON ECONF(14),GBUG2,BFOOD(14),PCHAR(14),ESPISH(14)
COMMON FOSARD,PNUP,REMIN,GBEN(14),PHUDGE,DUMMY,CVELI(12)
COMMON HUNGRY(2,14),A,B,BTIMES,EATEN,CURENT(12),WAVEE(12)
C
C
C   WIND PATTERN INDEX
C
      IW=IWTH(IWEEK,IDAY)
C
C   CALCULATE AREA OF THE LAGOON.
C
      ALAG=1.E6*(AREA(2)+AREA(3)+AREA(4)+AREA(5))
C
C   FRESHWATER RUNOFF (CU.M./DAY)
C
      IF(IWEEK.GT.1)GO TO 115
      ID=0
      XD=30.
```

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APPENDIX 1 (cont'd)

SUBROUTINE PHYS (cont'd)

```
      Q=1.E5
      GO TO 118
  115 ID=ID+1
      XD=XD+1.
C
C    CALCULATE THE KUPARUK RIVER FLOW, A FUNCTION OF THE TIME OF YEAR
C
      IF(XD.LE.100.)QK=Q1*EXP(Q11*XD)
      IF(XD.GT.100.)QK=Q2*EXP(Q22*XD)
C
C    CALC SAGAVANIRKTOK RIVER INPUT TO LAGOON (ONLY IF EAST WIND)
C
      QS=0.
      IF(IW.GT.4)GO TO 117
      IF(XD.LT.99.)QS=Q3*EXP(Q33*XD)
      IF(XD.GE.99..AND.XD.LT.108.)QS=Q4+Q44*XD
      IF(XD.GE.108.)QS=Q5*EXP(Q55*XD)
      QS=.015*QS
  117 CONTINUE
C
C    CALC TOTAL FRESHWATER INPUT
C
      Q=QS+QK
  118 CONTINUE
C
C    LAGOON WATER EXCHANGE RATE (/DAY)
C    OUTFLO IS A PRODUCT OF THE PHYSICAL OCEANOGRAPHY MODEL.  IT IS THE VOLUME
C    OF WATER PASSING THROUGH THE LAGOON PER DAY.  PHUDGE IS A PARAMETER FOR
C    TESTING THE SENSITIVITY OF THE MODEL TO CHANGES IN EXCHANGE RATE.
C
C
      OEX=(OUTFLO(IW)+Q)/TVOLW
      OEX=OEX*PHUDGE
C
C    EXPOSED AND PROTECTED SHORELINES (KM)
C    THE EXPOSED AND PROTECTED SHORELINES CHANGE WITH WIND DIRECTION.
C
      AREA(6)=EXPSHO(IW)
      AREA(7)=PROSHO(IW)
C
C    WAVE PERIOD (SEC.) AND LONGSHORE VELOCITY (CM/SEC) (PRODUCTS OF THE
C    PHYSICAL OCEANOGRAPHY MODEL).
C
      WAVE=WAVEE(IW)
      CURE=CURENT(IW)
      CVEL=CVELI(IW)
C
C    ICE THICKNESS (M)
C
      DO 110 IA=1,13
  110 DICE(IA)=XICE(IA,IWEEK)
      IF(IWEEK.GT.1)GO TO 101
      IF(IDAY.EQ.1)XTINO=0.
      XTINO=XTINO+TINO
      SUSP=0.
      DEPOS=0.
      OEX=0.
      WAVE=0.
      CURE=0.
      CVEL=0.
      GO TO 106
  101 CONTINUE
C
C    DEPOSITION AND RESUSPENSION OF SILT
C
      IF(ID.GT.1)XTINO=TINO
      SRATE=SLP(CVEL,CV,SR,2)
      DRATE=1./(CVK*CVEL+1.)
      SGAIN=XTINO*TVOLW
      DO 105 IA=1,10
      TSUSP=SUSP*TVOLW
      TDEPOS=DEPOS*ALAG
      SLOSS=TSUSP*OEX
      RSUSP=SGAIN-SLOSS+(SRATE*TDEPOS)-(DRATE*TSUSP)
      RDEP=DRATE*TSUSP -SRATE*TDEPOS
      TSUSP=TSUSP+RSUSP*.1
      TDEPOS=TDEPOS+RDEP*.1
```

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APPENDIX 1 (cont'd)

SUBROUTINE GEO (cont'd)

```
          IF(TSUSP.LE.0.)TSUSP=.1
          IF(TDEPOS.LE.0.)TDEPOS=.1
          SUSP=TSUSP/TVOLW
          DEPOS=TDEPOS/ALAG
      105 CONTINUE
      106 CONTINUE
          RETURN
          END
```

DATA INPUT FILE

```
S PRES(1,ALL)=0. 34. 497. 959. 25980. 51400. 46000. 41760. 21935. 106600. --OLDSQUAW AT 10-DAY I
S A=40.
S B=.03
S NTIMES=120. --FRACTION OF TOTAL DAILY INTAKE REPRESENTED BY FUNCTIONAL RESPONSE DATA
SET PRES(2,ALL) = 4*0. 280. 6800. 1467. 567. 526. 0 -- PHALAROPES
SET PRES(3,ALL) = 31 28 90 153 140 127 399 1000 125 3100 0  -- GULLS
SET CALCAT(ALL) = 430. 55. 560.
MACRO B1978
S PRES(1,ALL)=0. 22. 1200. 2482. 29500. 13340. 12372. 16683. 10153. 33500. --OLDSQUAW
SET PRES(2,ALL) = 4*0. 140. 3400. 730. 285. 265. 0. -- PHALAROPES

SET GRAMPC = 8.
SET ASC(ALL) = 5*1.E6 2*1000. 1.E6 1000. 1.E6 1.E6 1000. 1000.
SET IHAB(ALL) = 8 1 12 8 12 1
SET AREA(ALL) = 38. 157. 56. 12. 1. 35. 47. 20. 30. 100. 8.5 4.2 10.1
SET BENTH(ALL) = 0.
S BENTH(2)=.2
S ZOOIN(ALL) = 0. .005
S PHYIN(ALL) = 0. .05 .05 .05 .05 0.
S AICE(ALL) = 0. 1. 1. 1. 1. 0.
S BENIN(ALL) = 0. 1. .1 .1 .1 0.
S DETIN(ALL) = 0. .1 .1 .1 .1 0.
S DEFOL(ALL) = 0. .1 .01 .01 .01 0.
S CNIN = .05
S XSTP=3
S DELTP=.33
S GPMN=.75
S GRATE=.4
S SINKR=.07
S RPHYT=.2
S PHOUT(ALL)=.05
S OCNIT = .05
S RZOO = .1
S FLARV(ALL) = 0. .02 .05 .1 .05 .02 .01 0.
S RBEN=.015
S FIFR=1.8
S ZOOCN(ALL)=0. .005 .01 .02 .04 .05 .04 .02 .01 .005
S BENCR = .045
S FISHEP=2.82
S FISSER=.09
S FISHEF=.022
S ANAD(ALL,ALL)=0.
S ANAD(ALL,2)=0. .00001 .00003 .00003 .00003 .00003 .00003 .00003 .00001
S ANAD(ALL,3)=0. .00075 .00075 .0025 .0025 .0015 .0012 .001 .00075
S ANAD(ALL,4)=0. .0015 .0015 .005 .005 .003 .0025 .002 .0015
S ANAD(ALL,5)=0. .00001 .00003 .00003 .00003 .00003 .00003 .00003 .00001
S SFISHI(ALL,ALL)=0.
S SFISHI(ALL,2)=0. .0001 .0001 .0001 .0001 .0001 .0003
S SFISHI(ALL,3)=0. .002 .002 .002 .002 .002 .0064
S SFISHI(ALL,4)=0. .004 .004 .004 .004 .004 .0128
S SFISHI(ALL,5)=0. .0001 .0001 .0001 .0001 .0001 .0003
S OEXIN=.01
S BENIE(ALL) = 0
S VEG(ALL) = 5.
SET XMIG(1,ALL) = 200. 50. 7*0 900.  --  OLDSQUAW MIGRANTS
SET XMIG(2,ALL) = 10. 10. 6*0. 80. 120. -- EIDER MIGS
SET XMIG(6,ALL) = .1 10. 7*0. 1.6 -- TERN MIG
SET XMIG(5,ALL) = 50. 8*0 16. -- LOONS
SET XMIG(4,ALL) = 800. 1600. 6*0 1000. 1000.
SET XMIG(3,ALL) = 3.2 6.4 12.8 40. 0.
```

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APPENDIX 1 (cont'd) **BEST DOCUMENT AVAILABLE**

```
SET SHORE = 5   -- KM OF SHORELINE   E/W DISTANCE
SET EMAX = .15
SET FCWDAT = .9
S H(ALL)=0 2.5 0.5 0.5 0.5 0 0 1.0 0 0 0 0 3.
S Q1 = 1.53E6 -- CU.M./DAY FW RUNOFF PARAM
S Q11 = 0.02 -- FW RUNOFF PARAM
S Q2 = 1.56E9 -- CU.M./DAY FW RUNOFF PARAM
S Q22 = -0.05 -- FW RUNOFF PARAM
S Q3 = 2.5E7
S Q33 = -0.02
S Q4 = -2.3E8
S Q44 = 2.30E6
S Q5 = 3.49E5
S Q55 = -0.05
S IWTH(1,ALL) = 1 -- WEATHER INDEX(IWEEK,IDAY)
S IWTH(2,ALL) = 10 9 6 3 1 1 2 3 4 4
S IWTH(3,ALL) = 3 4 4 4 4 2 3 9 1 2
S IWTH(4,ALL) = 10 11 2 2 3 4 3 1 2 2
S IWTH(5,ALL) = 3 2 9 2 2 2 1 2 4 4
S IWTH(6,ALL) = 4 4 4 3 1 1 1 1 3 5
S IWTH(7,ALL) = 2 1 1 1 1 1 6 1 1 2
S IWTH(8,ALL) = 1 10 2 5 2 5 6 2 3 6
S IWTH(9,ALL) = 2 4 4 3 3 6 7 2 3 3
S IWTH(10,ALL) = 3 4 2 7 2 5 7 2 2 2
S EICE(ALL,ALL) = 0. — ICE THICKNESS(AREA,IWEEK) M.
S EICE(ALL,1) = 1.
S DACC(ALL)=0
S CVK = .07 --PARAM FOR SILT SINKING RATE
S SR(ALL) = 0. 0.8 -- PARAM FOR SILT RESUSPENSION RATE
S CV(ALL) = 15. 100.
S SUSP = 0. -- GM./CU.M. SUSPENDED SILT
S DEPOS = 0. -- GM. TCTAL DEPCSITED SILT
S OUTFLO(1...4) = 0.33E8 1.3E8 3.E8 5.2E8 -- ENE FLOW THRU LAGOON (CU.M./DAY), INDEXED BY IW
S OUTFLO(5...8) = .14E8 .55E8 1.E8 2.2E8 -- WSW WIND 2.5,5.,10.,20. M/SEC
S OUTFLO(9...12) = 0.14E8 .550E8 1.E8 2.2E8 -- NW WIND
S EXPSHO(1...4) = 41. -- ENE WIND EXPOSED SHORE (KM), INDEXED BY IW
S EXPSHO(5...8) = 48. -- WSW WIND
S EXPSHO(9...12) = 21. -- NW WIND
S PROSHO(1...4) = 86. -- ENE WIND PROTECTED SHORE (KM), IND BY IW
S PROSHO(5...8) = 79. -- WSW WIND
S PROSHO(9...12) = 106. -- NW WIND
S CURENT(1...4) = 5. 10. 50. 100. -- ENE WIND LONGSHORE CURENT (CM/SEC)
S CURENT(5...8) = 5. 10. 50. 100. -- WSW WIND
S CURENT(9...12) = 5. 10. 50. 100. -- NW WIND
S WAVPE(1...4) = 1. 2. 4. 7. -- ENE WIND WAVE PERIOD (SEC)
S WAVPE(5...8) = 1. 2. 4. 7. -- WSW WIND
S WAVPE(9...12) = 1. 2. 4. 7. -- NW WIND
S CVELI(1...4) = 5. 10. 50. 100. -- ENE WIND - AVG CURRENT IN LAGOON (CM/SEC)
S CVELI(5...8) = 5. 10. 50. 100. -- WSW WIND
S CVELI(9...12) =  5. 10. 50. 100. -- NW WIND
S TOPP(ALL)=0
S DEXTER(1...4) = .1  -- GRAMS C/CU. M./DAY INTO LAGOON FROM BOUNDARY A
S DEXTER(5...12) = .1 .2 .4 .6 .8  --SAME BUT FOR W-SW AND NW WINDS
S OCW(1...10) = 0. .07 .05  -- G N/CU.M AT BOUNDARY BY WEEK
S GINEX(1...4) = .4 .8 1.2 1.6  -- G INORGANIC MATTER/DAY/CU.M.WATER INTO LAGOON AS F(WEATHER TYP
S GINEX(5...12) = 2. 4. 8. 12.  .8 1.6 2.4 3.2  -- G INORGANIC MATERIAL PER DAY /CU. M. WATER IN
S GSLUSF=0.0  -- INITIAL DUMMY CCNDITION
S GEOG1=1.
S GEOG2=1.
S PHCDGE=1.
S GHIGH(ALL) = 0. -- HEIGHT OF AVERAGE SHORELINE SLUMP IN METERS
S GHIGH(6)=1.5
S GHIGH(7)=2.5
S GHIGH(12)=1.5
S GHIGH(13)=2.5
S GWIDSL(ALL) = 0. -- # KMS INTO SHORE LOST PER SLUMP
S GWIDSL(6)=1.3
S GWIDSL(7)=1.1
S GWIDSL(12)=1.3
S GWIDSL(13)=1.4
S GSLUMA(ALL)=.003 .006 .015
S GSLUSL(ALL)=0. 5. 7.
S GSEEPP(ALL) = 1.0
```

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APPENDIX 1 (cont'd)

```
S GA = .01   -- MINIMUM PROP DISPERSION DUE TO WAVE
S GB = 0.58 -- B PARAM.  IN ABOVE Y=A*EXP(BX)
S GC(ALL)=0. 3. 15.
S GD(ALL)=.01 .1 1. 1.   --  RELATION OF DISPERSION TO CURRENT
S GVOL(ALL) = 0.0
S GVOL(6)=3400
S GVOL(7)=6460
S GVOL(12)=400
S GVOL(13)=1760
S GSORG=0.
S GTING=0.
S GPORG(ALL) = 0. -- PROPORTION OF SLUMPED MATERIAL WHICH IS ORGANIC MATERIAL
S GPORG(6)=.3
```

PART 2. PHYSICAL PROCESSES

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March 1980

TABLE OF CONTENTS

Page

SUMMARY 55

ACKNOWLEDGEMENTS 57

INTRODUCTION 58

  Perspective and Data Sources 58

  Objectives and Rationale 58

    Objective 1--To Characterize Water Circulation and Exchange 59
    Objective 2--To Document Detritus Sources and Sinks and Describe Detrital Transport Mechanisms 60
    Objective 3--To Determine the Origins and Evolution of Nearshore Landforms 60

STUDY AREA AND THE REGIONAL ENVIRONMENT 61

WATER CIRCULATION AND EXCHANGE 64

  Seasonal Characterization 64

    Winter Ice Season 64
    Spring Thaw 65
    Open-Water Season 67

  Coastal Flushing 67

  Lagoon-Offshore Water Exchange 69

    Magnitudes of Exchange 70
    Mechanisms of Exchange 71

  Effects of Topography on Circulation 75

  Currents Near the Bottom 77

DETRITUS--SOURCES AND TRANSPORT 78

  Detritus Sources and Delivery Mechanisms 78

    Detritus from Stream Discharge 79
    Detritus from Shoreline Erosion 80
    Marine-Derived Detritus 80
    Relative Contributions--Riverine, Coastal, Marine 82

  Detritus Flux--Is the Nearshore Area a Trap? 82

    Detritus vs Inorganic Sediments 82
    Deposition of Terrigenous Detritus 83
    Detritus Flux Between Marine and Nearshore Areas 85
    Effects of Topography 86
    Depositional Evidence 86

TABLE OF CONTENTS (cont'd)

Page

GEOMORPHIC FEATURES AND THEIR EVOLUTION 88

  Formative Processes 88

    Barrier Islands, Lagoons and Estuaries--General Considerations 89
    Barrier Islands and Lagoons--Beaufort Sea 92

  Time Scales of Change 96

    Barrier Islands 96
    Lagoon Basins 97
    Mainland Coasts 99

CONCLUSIONS 99

LITERATURE CITED 101

SUMMARY

This report synthesizes and interprets, from reports of Barrier Island-Lagoon Program participants and from the general literature, data about selected oceanographic and geologic processes in coastal regions. Processes discussed are water circulation and exchange; detritus sources, transport mechanisms and sinks; and the origin and evolution of coastal landforms. The purpose of this synthesis is to provide information that promotes a realistic assessment of the ecological consequences of man's alteration of these processes in the Beaufort Sea.

Circulation regimes change seasonally in the Beaufort Sea. During winter, circulation is greatly restricted because of the ice cover, and exchange rates between lagoons and adjacent environments may be a small fraction of what they are in summer. Spring thaw and break-up (late May-early July) freshen nearshore waters and clear them of ice. Water exchange rates increase greatly in the open-water season that follows because there is no ice cover to hinder the effects of wind in driving the circulation.

In summer, lagoon waters are freely exchanged with adjacent nearshore waters, but mix relatively less with offshore waters. Lagoon-offshore exchange where rivers discharge is characterized by a net seaward movement of surface waters and landward movement of bottom waters, as is found in most estuarine situations. Circumstantial evidence suggests that coastal upwelling, which is not dependent on stream discharge, may also augment lagoon-marine exchange. Barrier islands retard rates of lagoon/marine exchange. Barrier islands, submerged bars, inlets, and other topographic features are both molded by and influence water movement, and some (e.g., inlets) develop characteristic locations and features in response to the existing coastal circulation patterns.

Currents near the bottom in coastal areas may be more important than currents at other levels from an ecological standpoint, because many of the biologically important materials and organisms (detritus, epibenthos) are concentrated on or near the bottom. Water movement near the bottom is characteristically retarded by the friction imposed by the substrate. In shallow coastal areas, effects of this friction are overcome most effectively by oscillatory, wave-generated motion in the water-column. This turbulence tends to resuspend benthic materials, which then are easily transported by unidirectional currents.

Two major documented sources of detritus to the nearshore Beaufort Sea are terrestrial--delivered by streams and eroded from coastlines--and these two sources are believed to provide similar volumes of organic detritus. Almost nothing is known about the amount of detritus that comes from offshore waters, but this source may be as important ecologically as terrestrial sources. What is generally known about sediments and detritus transport in coastal regions suggests that the nearshore region of the Beaufort Sea may serve as a trap for detritus from all three sources. Processes acting to cause the nearshore area to selectively accumulate detritus are the slowing of currents as detritus-laden streams enter the lagoons, the probable presence of landward-flowing currents near the bottom, and the effects of barrier islands in blocking seaward transport of detritus.

Most barrier islands of the world are thought to have been formed during the currently-existing post-glacial rise in the sea level by one or more of three mechanisms (1) sand thrown up by waves from the continental shelf, (2) elongation of sand spits by longshore transport, and their subsequent separation from the mainland, and (3) submergence of low-lying areas behind coastal ridges. Most Beaufort Sea barriers appear to have originated primarily through the third process (coastal submergence), but to have been extensively modified by ice and wave action and by longshore transport of mainland- and island-derived sand.

The expected persistence of topographic features on the Beaufort coast in their present form is short by geological time standards. Islands and shorelines may change shape considerably and migrate up to several meters annually. The tundra cover of most existing islands will probably persist for a few centuries at most. The barrier island-lagoon systems that exist, although expected to last more than several centuries, may naturally disappear within tens of centuries and be replaced by others as the sea advances onto the land.

ACKNOWLEDGEMENTS

Gratefully acknowledged for their participation in and contributions to the Barrier Island-Lagoon Workshop sessions, and for their enthusiastic adoption of field research programs to support the ecological disciplines, are the following persons:

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Dr. Brian Matthews (Oceanography; University of Alaska)
Dr. Sathy Naidu (Sedimentology; University of Alaska)
Dr. Donald Schell (Nutrients, Primary Production; University of Alaska)

Without these individuals the program could not have succeeded, and this report could not have been written. The extensive contributions they made toward developing an understanding of the physical processes operative in the Alaskan Beaufort Sea nearshore environment are referenced appropriately within this report. Their research is presented more fully in their own reports.

INTRODUCTION

It is well known that oceanographic and geomorphic processes regulate ecological processes in coastal areas in important ways. They should be investigated to understand how man's activities might affect the biota. However, all the ways in which physical processes influence the population processes of animals and plants are too numerous to study in a project of this sort. Fortunately for scientists trying to analyze impacts, each species of organism is affected significantly by only a few of the many processes occurring in an area, and not all of these will be affected by development. And, since this study emphasizes only a few species of organisms, the array of processes with which we must be concerned is very limited compared to the number that exists. Our purpose in this synthesis is to investigate physical processes that (1) strongly influence populations of selected key species of animals in the coastal environment, and (2) are affected by oil and gas exploration and development activities on the continental shelf.

Perspective and Data Sources

This section of the report synthesizes and interprets data from new oceanographic and geologic research conducted under the auspices of the Barrier Island-Lagoon Program, as well as from other studies conducted in the Beaufort Sea and elsewhere. The new research, conducted by the oceanographers and geologists participating in the Barrier Island-Lagoon Program, was essential for this synthesis. But additionally, because the funds and time available to these scientists were limited, information from other sources was used extensively. Most of this new research is published by NOAA/OCSEAP, and will be referenced by conventional citation. The Principal Investigators who conducted the research are acknowledged at the first of this report.

Objectives and Rationale

Three general objectives for physical process studies were established during the early planning stages of the program. These were

1. to characterize vertical and horizontal circulation patterns and water mass exchange characteristics in and near the barrier island-lagoon system,
2. to determine the sources and sinks of detritus and describe its transport mechanisms in the nearshore region, and
3. to determine the origins and evolutionary characteristics of the geomorphic features (barrier islands, lagoon basins, etc.) of the coastal region.

Some of these objectives were addressed by more than one of the Principal Investigators. In such cases, each investigator used a different research approach but coordinated his effort with his co-investigators.

Objective 1--To Characterize Water Circulation and Exchange

Circulation and exchange of water are ecologically important in coastal systems as a transport mechanism for detritus, dissolved nutrients, and many invertebrates. The ways in which these materials and organisms are suspended, carried, and deposited are governed by water circulation which, in turn, is a function of wind speed and direction, water depth and bottom topography. Likewise, coastal circulation and exchange patterns significantly influence the chemical and physical environments; during the open-water season relatively low salinities and high temperatures are maintained in the coastal waters, relative to those in the open ocean. This phenomenon appears to provide a favorable environment for certain invertebrates and fish.

Development may be accompanied by extensive alterations of nearshore topography through construction of solid-fill causeways and shipping channels, removal and/or connection of existing barrier islands, and in other ways that will affect circulation. Information about currents, water exchange characteristics (and associated patterns of material transport and temperature/salinity regimes), and how these are influenced by topography, is required for assessment of the short- and long-term effects of such activities.

Objective 2--To Document Detritus Sources and Sinks and Describe Detrital Transport Mechanisms

Organic detritus is an important energy source in the nearshore environment. It is replenished periodically from both terrestrial and marine sources. It is also moved about in nearshore lagoons and bays from time to time, and is transported to and from nearshore systems. Because fish and birds habitually congregate in the nearshore waters (as opposed to the adjacent marine system) to feed, it is important that the supply and maintenance of the detrital food base in these areas be continued.

Certain kinds of development structures may interfere with detritus transport to nearshore bays and lagoons. It becomes important, therefore, to document which detritus sources are critical, and to isolate which features of existing nearshore topography, circulation and water exchange are important factors in detritus accumulation. With such information, it would be possible to identify the kinds of development activities that would intercept vital sources of detritus or alter nearshore topography to adversely affect detritus accumulation.

Objective 3--To Determine the Origins and Evolution of Nearshore Landforms

A basic hypothesis being tested by this study is that lagoons and other nearshore areas provide important habitats for selected species and that these habitats are not replicated in adjacent marine waters. Evidence collected to date supports this hypothesis, and indicates that the difference between lagoon and marine ecosystems is influenced by the topographic configurations of the nearshore region. Maintenance of barrier islands and lagoon basins as topographic entities thus may be important as an environmental protection measure.

In order to determine the long-term impacts of development activities (such as removal of island material, stabilization of islands, and construction of shipping channels and causeways) to the integrity of the lagoon-barrier island system, the capabilities of the system to "mend" or regenerate itself must be known. Definition of the factors involved in the origin and maintenance of the barrier islands, lagoons, and other nearshore features has important implications with respect to the regenerative capability of these features. In other words, if historical evidence indicates that the magnitude of natural changes over short time periods exceeds and would obscure the changes to be caused by development, then it is likely that the system can absorb the impacts of man's activities with only short-term consequences to the ecosystem.

STUDY AREA AND THE REGIONAL ENVIRONMENT

The field research of the Barrier Island-Lagoon Program has focused on a relatively short section of the Beaufort Sea coast, Simpson Lagoon and vicinity (Fig. 1). The nearshore waters are shallow, and irregular, discontinuous chains of barrier islands skirt about 50% of the coastline. The island chains, which are generally parallel to the mainland, consist of islands that are characteristically low (1-1.5 m above sea level) and narrow (0.1-2.0 km wide); the islands range in length from a few hundred meters to 15 km. Offshore bars exist on the seaward sides of the barrier islands and along some stretches of exposed mainland coasts. The bottoms of unprotected nearshore areas are roughened by the gouging action of ice floes and icebergs.

Freezing of coastal waters begins in late September or October. Ice forms on lagoons first because they are more sheltered and brackish, and cool faster than the nearby ocean. During late fall and early winter, surface ice is still relatively thin and may be moved about considerably by wind; consequently, large areas of open water may periodically appear during this time. Ice thickens by about 1 cm per day throughout winter so that by April it is about 2 m thick. The ice begins to melt in May, and its rate of melt is soon accelerated near river deltas by river discharge.

In late May or early June waters from melting streams reach the coast; these streams carry large amounts of silt and detritus which they discharge into the nearshore environment. Sixty to 80 percent of the annual discharge of most streams occurs within several weeks after flooding begins, during which time nearshore waters are still ice-covered.

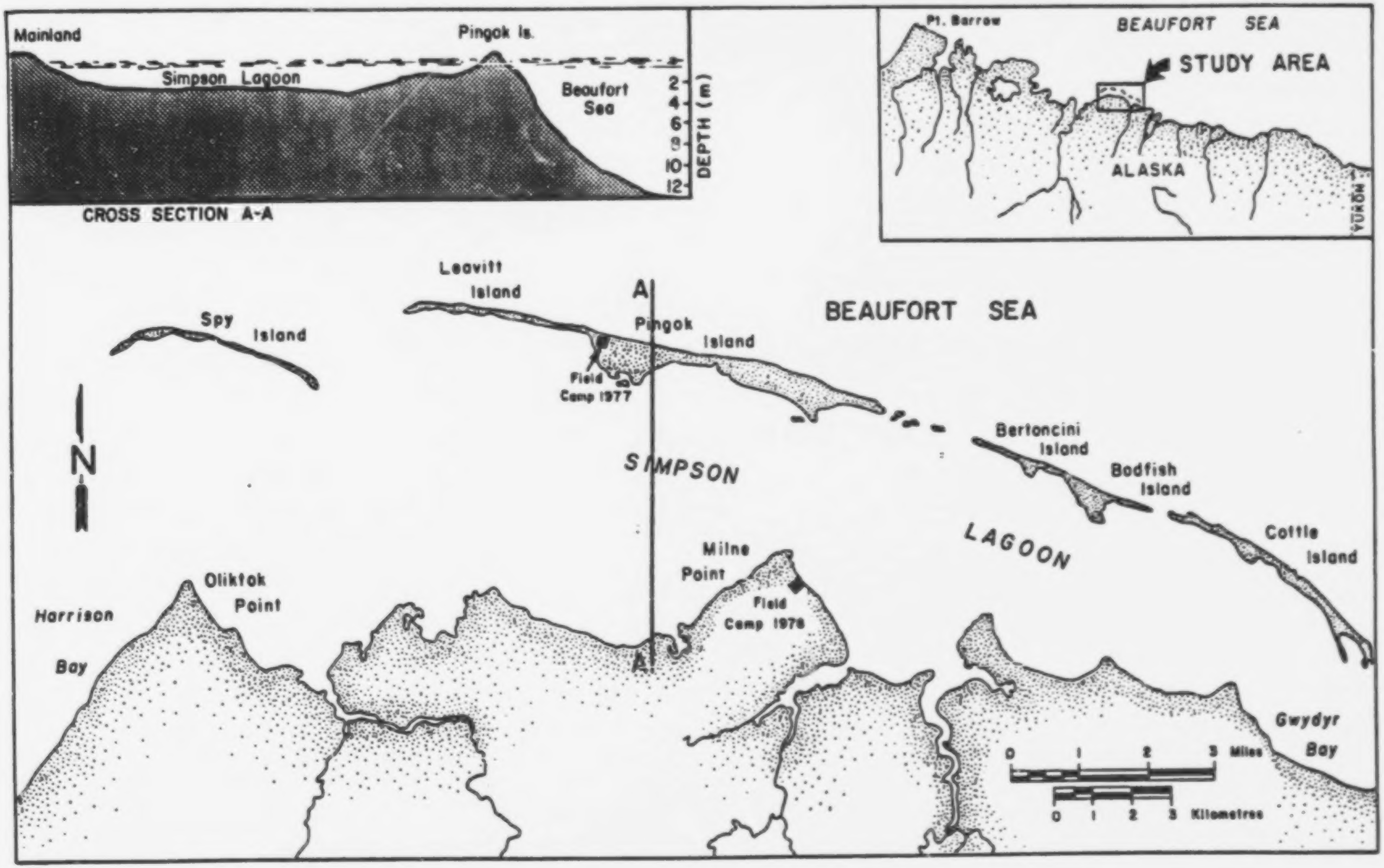
Mainland
Pingok Is.
Simpson Lagoon
Beaufort Sea
2
4
6
8
10
12
DEPTH (m)
CROSS SECTION A-A
Pt. Barrow
BEAUFORT SEA
STUDY AREA
ALASKA
YUKON
Leavitt Island
A
Spy Island
Pingok Island
BEAUFORT SEA
Field Camp 1977
N
SIMPSON
LAGOON
Bertoncini Island
Bodfish Island
Cottle Island
Milne Point
Field Camp 1978
Oliktok Point
Harrison Bay
A
Gwydyr Bay
0 1 2 3 Miles
0 1 2 3 Kilometres

Figure 1. Simpson Lagoon study area on the Beaufort Sea coast of Alaska.

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The water that reaches the coast first is discharged over the sea ice; most of this water eventually drains through cracks and holes to the water beneath. Within a few days, however, much of the ice adjacent to stream mouths has melted, allowing the river water to flow directly into coastal waters and thence under the ice. Discharges rapidly decrease during the course of the summer and are minimal by freeze-up.

During the open-water period the nearshore currents of the region are extremely variable and wind-dependent; astronomical tides are of secondary importance in affecting currents. Complex current patterns occur in nearshore circulation; these patterns are related to bottom topography, coastal configuration and presence of islands. Current speeds decrease as the winter ice cover forms and thickens.

During severe summer storms, high waters (storm surges) can inundate considerable portions of both the barrier islands and the nearshore mainland. The barrier islands limit the wind and wave action in the lagoon system, but the effects of wind and waves in exposed coastal waters are limited only by distant points of land, by the distance to the edge of the ice pack, or by concentrations of ice floes.

Because of wave, tidal and ice action and a gradual historical rise in sea level relative to the mainland, the mainland coastline retreats on an average of 1-2 m annually, and the island margins are also eroded away and reworked. This erosion is episodic in nature; most occurs during intense storms. At such times large amounts of organic material (tundra mat and underlying peat) and inorganic sediments are transported from mainland and island shores to lagoon and marine environments.

Most inorganic sediment particles in the lagoons and other nearshore basins are the size of sand or silt; gravels occur sparingly. Sediments are poorly sorted because sediment resuspension and transport by currents and wave action is extremely variable. Sediments are continually being introduced to nearshore areas via river floodwaters and coastal erosion. Wind-generated waves and currents produce a net westerly longshore sediment transport.

WATER CIRCULATION AND EXCHANGE

The important questions related to water circulation and exchange are listed below; the ecological significance of each question is explored in the paragraphs that follow.

1. What are the nature and timing of seasonal changes in the nearshore circulation regime?
2. What are the flushing rates of a typical coastal lagoon system under a range of expected conditions?
3. What are the magnitude and nature of exchange between coastal and marine waters?
4. How are circulation and water mass exchange affected by topographic features?
5. What are the magnitudes of the currents affecting coastal benthic environments?

Seasonal Characterization

In high-latitude environments, organisms have life histories that are structured rigidly by seasonal environmental phenomena. Because circulation and water mass movement strongly influence animal consumers and their supporting food chains in the nearshore Beaufort Sea, it is important to accurately define the seasonal nature of these processes in order to assess the ecological implications of oceanographic processes in general.

Winter Ice Season

Ice usually begins forming on the lagoon surfaces in late September or early October. Sheltered lagoon waters begin to freeze earlier than the nearshore ocean because the shallow waters cool more quickly and, because they are brackish, freeze at a higher temperature (Wiseman and Short 1976). From this time until the following April, ice increases in thickness at an average rate of about 1 cm per day. During October, November and December, the nearshore circulation beneath the ice is relatively unimpeded. Severe storms that occur during this period can move the ice about freely, causing large ice-free leads to form and ice to move offshore or to pile up on the shore (Barnes and Reimnitz 1977; Weller et al. 1978:60).

As the ice thickens, the effects of winds on the underlying waters are damped, but under-ice movement otherwise remains relatively unrestricted until channels and passes begin to be blocked by ice. In Simpson Lagoon this occurs when ice reaches 1.2-1.5 m in thickness (Schell and Hall 1972). Even when unimpeded by ice blockage, the rates of water movement and associated sediment suspension and transport under ice are much lower than during summer (Drake 1977).

During late winter (March, April, early May) when the ice is thickest, sub-ice water flow is at a minimum (Schell and Hall 1972; Weller et al. 1977:41). At this time lagoons and bays may experience little or no flow, and currents in nearshore areas are generally less than 5 cm per second. Circulation in the nearshore may be enhanced at this time by thermohaline convection, a seaward-landward water exchange generated by the production of high-salinity water in shallow areas by salt exclusion during freezing (Weller et al. 1977:151; Schell 1978). Under such conditions, the highly saline water produced at the water-ice surface sinks and flows seaward at the bottom, and is replaced by a landward flow of lower salinity water near the top of the water-column.

Spring Thaw

The relatively steady state of low to zero circulation in coastal waters from March to May is quickly and drastically altered by spring flooding of rivers, which usually begins during the last week in May or the first week in June. Although variable in magnitude, characteristics of spring thaw are similar among North Slope rivers and coastal segments; the following descriptions are from Barnes and Reimnitz (1972), Reimnitz and Bruder (1972), Walker (1974), Wiseman and Short (1976), and Weller et al. (1978:110).

Spring floodwaters from Alaskan arctic rivers flow over the river delta and then onto the coastal ice if river delta channels are shallow and frozen throughout. In rivers such as the Colville that have deep delta channels some of the initial flow goes under the river delta ice and the sea ice.

As the initial discharge moves seaward, it fans out rapidly over the nearshore ice, reaching depths of a meter or so and depositing much silt and detritus on the ice. This flood lasts for only a few days; much of the water finally drains through holes and cracks into lagoon and nearshore marine waters. Also, sea ice immediately adjacent to the deltas is soon melted, allowing the river water to flow directly into the sub-ice water.

The floodwater injected beneath the ice advances seaward as a freshwater wedge or lens between the ice and the more saline waters beneath, to the approximate extent of the over-ice discharge. (The sub-ice lagoon and river delta waters are highly saline immediately preceding flooding because the solutes have been excluded and concentrated under the ice during the freezing process.) Little mixing of the fresh and saline waters occurs immediately, although some of the material suspended in the river water settles through to the bottom.

Typically the over-ice floodwaters quickly cover large portions of the surfaces of the lagoons or bays at the river mouths, and a small portion of the over-ice floodwaters extend beyond to the marine environment. The water on the ice generally flows westward; the river water that flows under the ice presumably does likewise.

Intense flooding normally lasts less than two weeks, after which the under-ice water in some of the lagoons and bays is almost completely fresh except for pockets of saline water in bottom depressions. As the surface ice melts in the following weeks, the fresh water gradually mixes with incoming cold marine water to create the brackish water systems that prevail along the coast throughout the summer.

During the month following initial over-ice flooding, bay and lagoon ice typically thins in place, melting first where deposits of silt and detritus have darkened the surface. Because of this differential melting, most of these deposits are probably dropped in place rather than being rafted away (Reimnitz and Bruder 1972). In early June the thin ice finally begins to break apart and move; by mid-July the ice remnants have normally moved out with the winds and currents, leaving the lagoons and bays open.

Open-Water Season

The open-water season is the period during which surface ice offers little obstruction to the action of wind on coastal waters. Although variable in length, this period normally lasts about three months, from early July to early October.

Nearshore currents in the open-water season are primarily wind-driven (Wiseman et al. 1974; Callaway and Koblinsky 1976; Dygas and Burrell 1976; Matthews 1978; Mungall 1978; and others). Winds are predominantly from the northeast and secondarily from the west. Currents in the nearshore move parallel to the coast and in the same general direction as the wind.

The most intense storms come from the west, at irregular intervals, but primarily late in the open-water season (sometimes well into the early winter). These late-season storms are responsible for the largest storm surges and for the majority of coastal erosion (Short et al. 1974; Weller et al. 1978).

Freshwater input from most rivers decreases by the beginning of the open-water season, and remains relatively low throughout the open-water season (Barnes and Reimnitz 1972; Reimnitz and Bruder 1972; Walker 1974; and others), although the flow pattern varies somewhat among rivers (Fig. 2).

Coastal Flushing

The flushing rate of waters in lagoon and other nearshore environments needs to be evaluated because it is an index of the integrity of the nearshore system. If water and its entrained organisms and materials are rapidly transported through a coastal segment, then the integrity and distinctness of that area, *in terms of the water and its load*, are low. This is an important consideration when extrapolating information from one part of the coastal system to another and when predicting the persistence of local anomalies in water quality. Effects of flushing rates and characteristics on the transport of suspended materials are especially important; the rate of supply of food-chain materials to sites where food may have been depleted depends on the rates

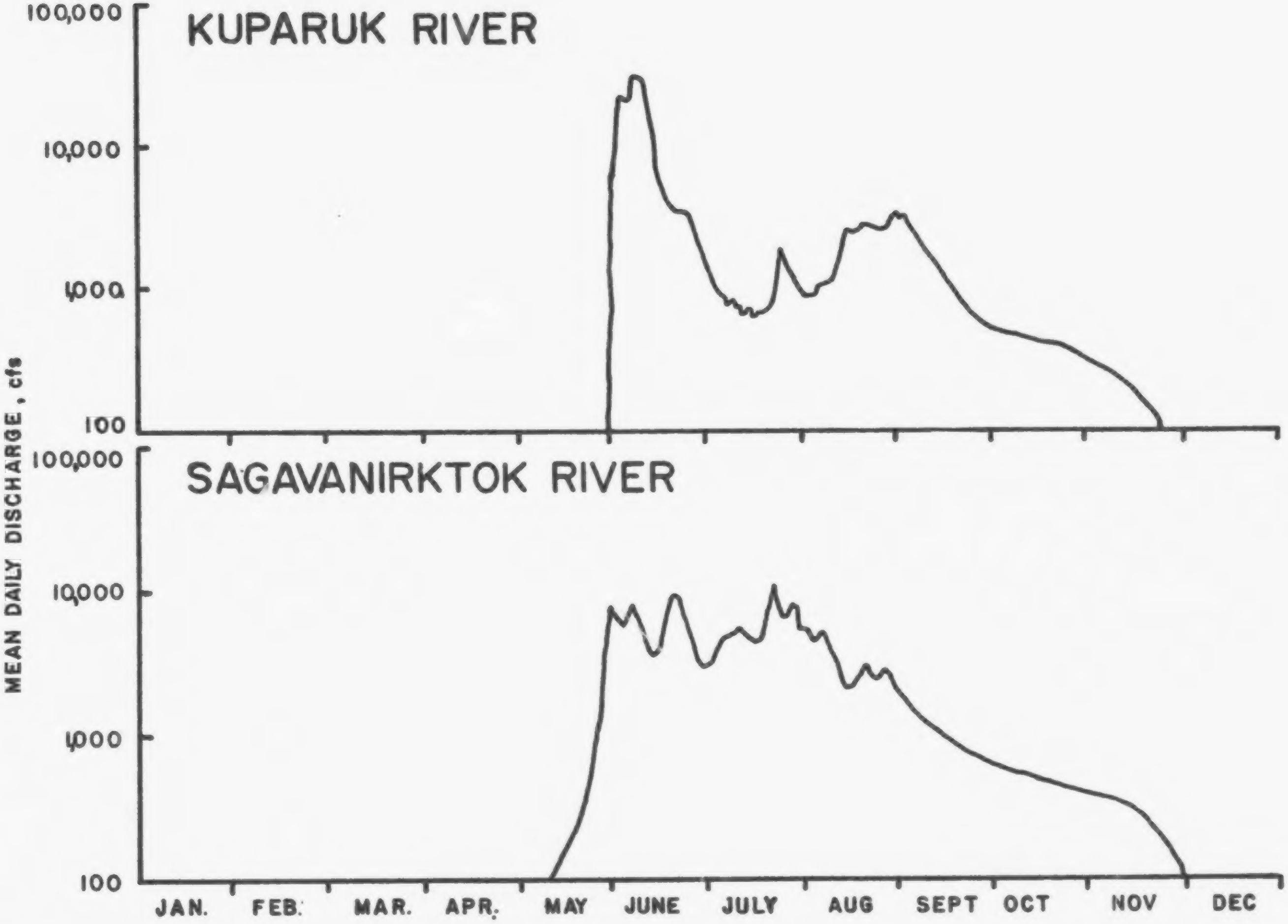

Figure 2. Annual hydrographic regimes of two rivers discharging into the Alaskan Beaufort Sea. (Adapted from Carlson et al. 1977).

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and nature of transport processes. Similarly, the rate of flushing determines the rapidity with which coastal sites are exposed to changing arrays of physical and chemical water conditions.

In summer, currents in shallow coastal waters generally move parallel to the coast at about 3 to 4% of the speed of the wind and in the same direction as the wind (Callaway and Koblinsky 1976; Mungall 1978). Summer winds are usually from the northeast and average about 5 m per s. The coastal waters will move westward under these conditions at about 15 cm/s, causing a coastal area the size of Simpson Lagoon (about 35 km long) to flush in about five days. Under the influence of strong winds, the same system could flush in one day (Mungall 1978). Since wind-driven currents in such shallow waters are normally uniform throughout the water-column except very near the bottom (Komar 1976a), such flushing may be virtually complete except for bottom waters and those affected by coastline irregularities. However, as I will describe later, the ecologically important currents may be those at the bottom that are resistant to flushing.

Currents under ice apparently also move parallel to the coast, but at rates much reduced from those of summer (Schell and Hall 1972; Barnes and Reimnitz 1977). Flushing rates for winter have not been calculated, except that they are presumably reduced to essentially zero in lagoons when inlets become sealed by ice (e.g., Schell and Hall 1972).

Lagoon-Offshore Water Exchange

It is implied above that rapid coastal flushing is caused mainly by water mass exchange parallel to the coast. However, it has not been established what proportion of the water that flushes coastal systems comes from adjacent offshore marine areas. The following discussion addresses the ecological importance of the difference between movement of water along the coast and coastal-marine exchanges, and documents what is known about water exchange between nearshore lagoon and offshore marine areas.

Water exchange between coastal and marine environments appears to be extremely important to animals in the coastal region; whether the exchange is ecologically beneficial or harmful may depend largely on its nature and rate. First, for selected species, the nearshore water may offer beneficial conditions (presumably related at least partly to water quality or entrained materials) in comparison with waters in the marine system (Truett 1980). Therefore, for the benefit of these species, exchange rates between nearshore and marine water needs to be low enough to prevent excessive dilution of coastal waters by marine waters. Second, exchanges of transported materials (invertebrates, detritus, nutrients) between the coastal and marine environments may be vital to the well-being of coastal biota. From this point of view, water exchanges need to remain sufficiently great to maintain these vital transport processes. It is important, then, that the magnitudes and mechanisms of coastal-offshore water exchange be examined, especially since proposed development activities (construction of causeways, etc.) may affect exchange characteristics in ecologically important ways.

Magnitudes of Exchange

Partially enclosed bays and lagoons along the Beaufort Sea coast become progressively more isolated and different from the marine environment as the surface ice thickens in winter (Schell and Hall 1972; Weller et al. 1978). The waters of the two environments may actually become physically separated by ice barriers, and salinities in the lagoons and bays may approach or exceed the physiological tolerances of some of the animals that utilize the lagoons in summer (Griffiths and Dillinger 1980).

The exchange rate (and the resulting integrity of the nearshore system) during the summer appears to be a more critical issue. Biologists participating in this study (P. Craig, W. Griffiths) report that during summer lagoon water temperatures are higher and salinities lower than they are in the adjacent ocean. Matthews (1978) shows that the temperatures of the coastal waters remain distinctly higher in summer than do the temperatures of the adjacent marine system. Mungall (1978) documented that salinities and temperatures within the lagoon, although variable, remain generally lower and higher, respectively, than those in offshore areas. These temperature and salinity differences have also been reported by Hufford (1974), Wiseman et al. (1974), Herlinveaux and de Lange Boom (1975), Schell (1975), and others. Matthews (1978) and Mungall (1978) thought that they could trace the coastwise movement of water boluses. Matthews concluded that mixing between the nearshore and marine water masses was minimal, since the temperature and salinity differences between the two areas persisted throughout the open-water season. Callaway and Koblinsky (1976) also implied that exchange between the nearshore and marine systems was very much less than exchange between nearshore subsystems.

Mechanisms of Exchange

The evidence cited above indicates that coastal waters normally do not mix with offshore marine waters to a great extent. However, some exchange between the two systems does occur. The mechanisms of exchange are important to the transport of entrained materials (to be discussed later) as well as to the maintenance of the characteristic warm, brackish waters in nearshore areas.

Exchange processes characteristic of shallow lagoons and estuaries in more temperate zones presumably also occur along the Beaufort coast in summer when waters are ice-free. It should be noted that most lagoons and bays in northern Alaska are by definition estuaries, i.e., "semi-enclosed coastal bodies of water which have free connections with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage" (Cameron and Pritchard 1963). The following paragraphs discuss important aspects of estuarine-marine exchanges.

The dominant mode of exchange between estuarine and marine environments, even in the case of partially- to well-mixed estuaries (as are most of the Beaufort lagoons and bays), involves seaward flow of brackish water in the surface layers and landward flow of saline water in lower layers (Conomos and Peterson 1976; Dyer 1978; Officer 1978; Pritchard 1978; Conomos 1979; and others) (Fig. 3). In the Beaufort Sea this phenomenon apparently occurs even under the nearshore ice during spring runoff, as described earlier. However, during and for some time following the peak runoff period the interface between the overlying freshwater wedge and the underlying salt water wedge may be seaward of some of the very shallow lagoons, judging from under-ice salinity measurements made in Simpson Lagoon in June 1978 (W. Griffiths, pers. comm.). Consequently, waters of some Beaufort Sea lagoons at this time may be almost completely fresh because of the tremendous under-ice flushing action from major rivers. During the open-water season in the nearshore Beaufort Sea, the mixing effect of winds obscures this two-directional stratified flow in the shallow lagoons. However, sensors monitored by Barnes et al. (1977a) showed that under prevailing easterly winds in Stefansson Sound, cold saline waters entered the sound on the bottom of passes as the warm brackish water exited at the surface. Similarly, Schell (1975) found that pronounced stratification developed in Simpson Lagoon during calm weather in late summer, apparently because of the intrusion of sea water at the bottom. Herlinveaux and de Lange Boom (1975) noted characteristic intrusions of high-salinity waters in summer at the bottoms of southern Beaufort Sea lagoons in Canada. Furthermore, steep salinity gradients (differences of 6% per m depth) have been noted at relatively deep entrances to Simpson Lagoon at the same time that the lagoon waters themselves are fairly well mixed (Weller et al. 1978:67). Stratification caused by surface freshwater outflow is more evident in the deeper waters outside the lagoons than within the lagoons (Hufford 1974).

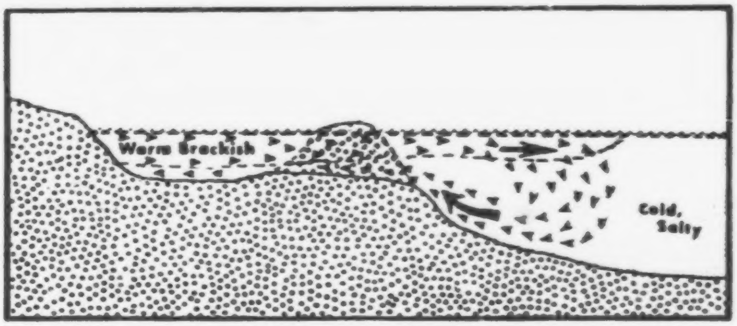

Figure 3. Characteristic estuarine circulation patterns cause brackish water to move seaward at the surface and saline water to move landward at the bottom. Particulates tend to settle and exhibit a net landward movement.

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Related to this layering phenomenon is the process of coastal upwelling, whereby deep, cold marine waters are brought to the surface near the land margin. Upwelling is a common occurrence in many coastal areas of the world (Johnson 1957; Segerstrale 1957; Conomos and Peterson 1976; and others) and may occur simultaneously with the estuarine-marine mixing processes described above. Upwelling is probably common along the southern Beaufort Sea coast; the postulated causes and characteristics are described below from Hufford (1974), Wiseman et al. (1974), Herlinveaux and de Lange Boom (1975), Barnes et al. (1977a, b), and Drake (1977).

Upwelling along the Beaufort coast typically occurs when winds are from the east during the open-water period. Under these conditions, the sea level is lowered, and the warm, brackish coastal waters tend to be pulled seaward as a surface lens, and the cold, saline marine waters intrude landward at the bottom (Fig. 4). This type of circulation pattern should be expected to occur commonly since the summer winds are predominantly from the east (Barnes et al. 1977b). (It should be noted that winds from the west typically raise coastal water levels by pushing water into the coastal bays and lagoons; the warm brackish coastal waters under these westerly wind conditions are held against the coast where they are warmed by the sun and freshened by runoff [Wiseman et al. 1974].)

It is likely that the presence of barrier islands tends to retard both the seaward transport of the coastal waters and the landward transport of marine waters, and that nearshore-offshore exchange would be more rapid along exposed coasts. The fact that the coastal bay and lagoon waters tend to remain relatively warm and brackish throughout the open-water season indicates that the exchange processes are not sufficient to thoroughly mix lagoon waters with marine waters. However, as discussed later, both the typical estuarine flows and upwelling may cause significant shoreward transport of materials entrained in the water near the bottom.

In winter, normal advective exchange between marine and nearshore areas is assumed to be slow, although there is little conclusive information. However, Schell has postulated (in Weller et al. 1977:151; Schell 1978) a sub-ice convective exchange mechanism, the magnitude of

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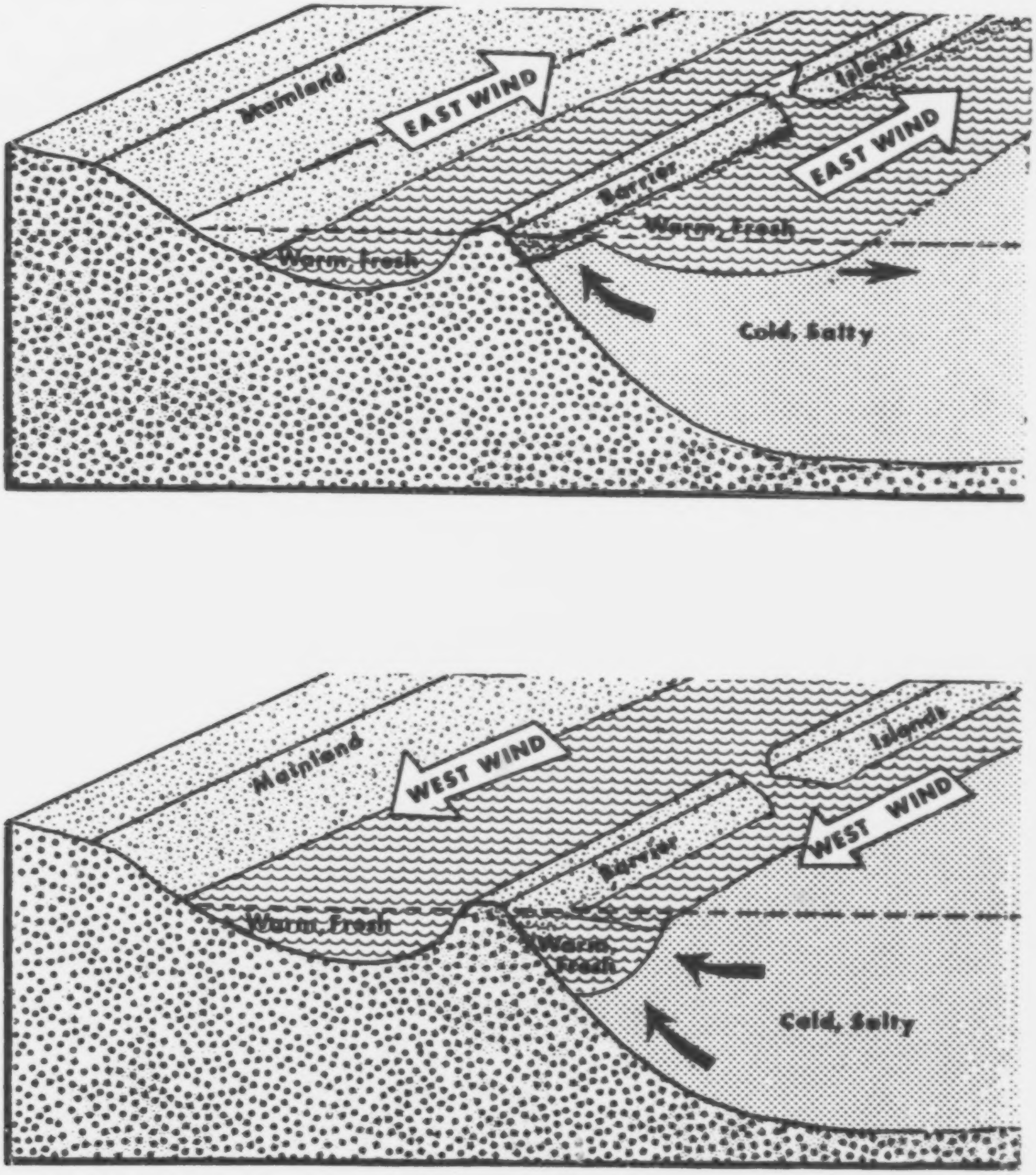
Mainland
EAST WIND
Islands
EAST WIND
Barrier
Warm, Fresh
Warm, Fresh
Cold, Salty
Mainland
WEST WIND
Islands
WEST WIND
Barrier
Warm, Fresh
Warm, Fresh
Cold, Salty

Figure 4. Winds from the east along the southern Beaufort Sea coast tend to depress sea level and cause upwelling near the land margin; those from the west hold brackish water against the shore and raise the sea level.

which is uncertain but the importance of which in supplying nutrients may be significant.

Effects of Topography on Circulation

Topography appears to affect nearshore water motion in several ways that are potentially important to biota. As indicated above, the presence of barrier islands may be important to the maintenance of physically warm, brackish waters in biologically active coastal regions. Some water birds (e.g., phalaropes and arctic terns) appear to congregate to feed in the lagoon near lagoon entrances (Johnson and Richardson 1980); it is hypothesized that currents may selectively deliver and/or affect availability of entrained food organisms to birds, as well as other organisms, at these sites. The configuration of the nearshore bottom and emergent landforms may determine the effectiveness of coastal areas as detritus and sediment traps.

It is well known that all anomalies in the topography of the nearshore bottom and of the coastline have an influence on nearshore circulation (Mooers 1976). Islands, coastal capes, and submarine banks form barriers to flow. Coastal embayments, depressions and submarine canyons may form channels for flow. Since the interactions of flow with topography are governed by predictable physical laws, extrapolations and comparisons among coastal regions are possible (Mooers 1976).

Barrier island chains have characteristic inlet features, or passes, that are maintained by water movement, and that, in turn, control water movement (Emery and Stevenson 1957; Riggs 1976). These passes form or change in direct response to the basic hydraulic pressures within the coastal system; they open by erosion and close by shoaling of sediments to fit the hydraulic pressures at any given time. Passes in the vicinity of rivers are generally larger and more stable than other passes because they carry much of the freshwater discharge. Inlets that are predominantly tidal tend to be more ephemeral; they are generally formed by storm waves, kept open by tidal currents, and closed or moved by storms or longshore currents. If closed, they will tend to recur within the same general area, when needed to accommodate discharge. Because inlets must periodically accommodate rapid water discharge, they are usually the deepest part of a lagoon or estuary area.

Inlets in the barrier island chain skirting Simpson Lagoon and Gwydyr Bay appear similar in structure and function to those reported for other systems. The tidal inlets are generally shallow compared to the major inlet (Egg Island Channel) which accommodates the Kuparuk River discharge (Matthews 1978; Mungall 1978). Some of these tidal inlets have been observed to close and reopen (Cannon and Rawlinson 1978; W. Griffiths, pers. comm.). Inlet depth in the Simpson Lagoon area, particularly of the major inlets, is usually greater than that of the adjacent lagoon, and water flow through the inlets is often rapid.

It has been found that inlet position and shape are critical to the circulation and the ecology of lagoon systems in temperate regions (Copeland 1974; Mooers 1976; Warme et al. 1976; and others); the same has been implied for the Alaskan arctic coast (Schell and Hall 1972; Faas 1974; Matthews 1978; Mungall 1978; and others). The nature and magnitude of lagoon flushing in winter depends on the locations and depths of major inlets; under-ice flows decrease or cease as inlets are sealed by thickening ice, and water salinities in lagoons increase rapidly thereafter (Schell and Hall 1972; Weller et al. 1978:110). Introduction of cold, saline marine water to lagoons in summer by landward intrusion and upwelling processes may be regulated by inlet depth, since marine waters normally must enter at the bottom beneath the exiting brackish water. Longshore flushing rates of lagoons in summer also depend on the flow capacities of lagoon entrances, and the effectiveness of transport of entrained organic and inorganic materials into and out of lagoons may depend on inlet location and depth, as will be discussed later.

The barrier islands have both direct and indirect effects on circulation. They physically obstruct water movement and exchange so that the discreteness of the lagoon from the sea is enhanced. They also obstruct wind motion so that the effect of wind on adjacent waters is altered, although the changes in general circulation patterns as a consequence of such effects is not well known (Bowden 1978; Hamilton and Rattray 1978; Hsu 1978).

Wind-driven currents in shallow waters behave similarly regardless of depth except immediately above the bottom. Here gradients in current speeds are very sharp because of frictional drag that retards the water motion (Carriker 1967; Komar 1976a, b; and others). The theoretical considerations and consequences related to currents in benthic environments are discussed in the next section.

Currents Near the Bottom

Water motion near the bottom is biologically important for several reasons. Bottom currents erode important sites (e.g., inlets). The resuspension and deposition of organic detritus, and perhaps dissolved nutrients, depends on bottom currents. Some of the important epibenthic organisms (e.g., mysids, amphipods) may make behavioral adjustments to bottom currents in order to accomplish critical movements to, from, and within the nearshore lagoons.

Because of friction-caused retardation of flow near the bottom, considerable motion must be present in the mid-water zone before there will be movement of benthic particles or organisms. Three kinds of processes result in significant water motion near the bottom--unidirectional currents, oscillatory motion associated with waves, and localized scouring (caused by a focusing of unidirectional flow). There is some disagreement as to whether unidirectional currents or wave motions are most important to resuspension and transport of materials (Komar 1976b). However, there is general agreement that in shallow shelf waters under a given wind regime, the shear stress exerted on the bottom by oscillatory wave motion is several times larger than the shear stress associated with the unidirectional current (Komar 1976b; Madesn 1976). It appears that wave action is most important in resuspending bottom materials, whereas unidirectional currents are more important in causing net transport of already-suspended materials (Komar 1976b). Focused bottom scouring is a local phenomenon; in the Beaufort Sea it is associated with rapid water motion through holes or cracks in ice (Reimnitz and Bruder 1972) and, as elsewhere (Emery and Stevenson 1957; Riggs 1976; and others) at narrow inlets or passes. The importance of scouring appears to be more in shaping *local* benthic environments than in contributing to the total resuspension and transport over a large area.

Because of the extreme difficulty in measuring currents at the bottom (Carriker 1967), few empirical data are available about the relationships between winds, waves and surface currents, and bottom currents. The effects of these interactions on the vertical resuspension of bottom materials are especially poorly known (Komar 1976b; Kjerfve et al. 1978; Schubel et al. 1978). During storms on Alaska's arctic coast, high sediment and detrital loads suspended in the water indicate that considerable water motion occurs on lagoon bottoms, but there is no knowledge of the magnitude of this motion at varying bottom depths, current speeds, wave periods, and wind speeds.

DETRITUS--SOURCES AND TRANSPORT

From the viewpoint of ecosystem functioning, there are two important questions about dynamics of detritus movement in the nearshore environment:

1. What are the sources and mechanisms of delivery of detritus to the nearshore?
2. Is the nearshore environment a detritus trap, and if so, what physical processes and environmental features are involved?

Detritus Sources and Delivery Mechanisms

Detritus appears to be a primary nutrient source and a secondary energy source for nearshore food webs (Schell 1979). Most of the detritus found in the nearshore area is not produced *in situ* but delivered there from external sources. It is important, therefore, to document where the detritus comes from and what processes deliver it to the coastal regions.

Three potentially important detritus sources and delivery mechanisms have been identified:

1. terrestrially-derived detritus from the drainage systems of the larger streams that discharge into nearshore areas,

2. terrestrially-derived detritus from coastal erosion, and
3. marine-derived detritus transported landward.

Detritus from Stream Discharge

River discharge has been found to be a major source of detritus to nearshore lagoons and estuaries in many temperate areas (Fox 1957; Hedgpeth 1957; Segerstrale 1957; Copeland 1974; and others); it has also been reported to contribute large amounts of organic materials to the nearshore Beaufort Sea (Reimnitz and Bruder 1972; Walker 1974; Pelletier 1975; Cannon and Rawlinson 1978; and others). The general characteristics of the discharge of stream-borne detritus and sediment into the Alaskan Beaufort Sea have been documented (Barnes and Reimnitz 1972; Reimnitz and Bruder 1972; Walker 1974; Pelletier 1975; Cannon and Rawlinson 1978). Almost the entire annual increment is brought to the coast in June, carried by the rivers during the peak runoff period. The organic and inorganic suspended materials are mixed; the organics range in size from very small particles to peat shreds to driftwood. The percentage of organic material in the suspended load is estimated (for the Kuparuk River) to be about 1% (Cannon and Rawlinson 1978, quoting D. Schell, pers. comm.). The suspended load is deposited in part on the nearshore ice surface and discharged in part beneath the ice (Walker 1974); Cannon and Rawlinson (1978) believe that the majority of the organic fraction is carried in the early overflow and deposited on top of the ice.

It appears likely that the majority of the detritus, even though a large portion is initially discharged above the ice, reaches the water-column in or near the coastal lagoons and bays. Most of the water which initially flows over the ice quickly finds its way, via cracks and holes, to the underice environment within and near the bays and lagoons (Barnes and Reimnitz 1972; Cannon and Rawlinson 1978). The sediments remaining on the ice in the lagoons are not moved appreciable distances until the ice breaks up and leaves the lagoons in late June and early

July. By this time most of the ice underlying the deposits of detritus (which are darker than exposed ice and thus heat more rapidly) has melted in place, releasing the detrital materials to the water beneath.

Detritus from Shoreline Erosion

It has been known for many years that coastal erosion accounts for large amounts of detritus in nearshore waters of the Alaskan arctic. MacGinitie (1955) reported that tundra vegetation and peat were eroded into the nearshore Beaufort Sea at Barrow. More recently, Short et al. (1974), Schell (1975, 1978), Lewis and Forbes (1975), and Cannon and Rawlinson (1978) have described coastal erosion as detritus sources elsewhere in the southern Beaufort Sea.

The organic material released to nearshore waters by coastal erosion is largely peat, which underlies the tundra vegetation in thicknesses up to a meter or more. This peat is eroded primarily during storms, when wave action reaches across the beaches to the peat-capped bluffs on the mainland and islands. The major inputs probably occur in late summer and early fall under the action of winds from the west.

Indirect evidence indicates that seaward transport of detritus from coastal erosion is relatively slow. Large lumps of tundra mat are commonly encountered on the beaches fronting bluffs and in shallow waters near these beaches, but not in deeper waters in mid-lagoon. Naidu (1978) found organic carbon levels in sediments to decrease with distance from mainland shores. Westerly storms, which cause the most severe coastal erosion, also tend to hold the coastal water masses against the shore, thereby impeding seaward transport of suspended particulates.

Marine-Derived Detritus

Whether a significant portion of marine-produced detritus (e.g., dead plant and animal remains) finds its way to the coastal estuaries and lagoons along the Beaufort coast is unknown. Schell (1978) implied that nearshore marine sources of detritus (sinking plankton, etc.) may be ecologically significant, but indicates that data supporting that view are not yet available.

The major components of detritus produced within coastal and marine waters are sinking phytoplankton, dead animals, animal parts, and metabolic products. The importance of sinking plankton in shallow, turbulent coastal waters is uncertain; the plankton may remain suspended because of their low specific gravity (Bellis 1974; Kremer and Nixon 1978:56). However, in winter, settling under ice, even in shallow water, should not be affected by excessive turbulence. Settling rates also become significant in the open ocean where waters are deeper and, below the surface layer, less turbulent (Kremer and Nixon 1978:56).

Little information about the landward-seaward flux of organic detritus is available; descriptions of how inorganic sediments behave in coastal waters are more common. Bellis (1974), Hatcher and Segar (1976) and Naidu (1978) have assumed that organic detritus is similar to inorganic fines (clay, silt) in response to current action. If this is true, then we may gain insight about detritus transport by examining information about interactions between inorganic sediments and water along coasts. Johnson (1957) and Drake (1976) noted that current patterns over the inner continental shelves of the world typically concentrate resuspended sediment in the nearshore zone. Dyer (1978) showed that the mechanism that drives sea water toward land near the bottom in typical estuarine circulation systems also returns the sediments to the coastal waters; he found a net landward dispersion of sediments in two well- to partially-mixed estuaries in France and the United Kingdom. In San Francisco Bay, Conomos and Peterson (1976) found that significant portions of sediments dispersed seaward in the water-column were returned to the bay in bottom, landward-flowing currents.

To conclude, it is not known if much marine-derived detrital material is transported to the nearshore lagoons and estuaries of the Beaufort Sea. However, evidence from other coasts suggest that coastal circulation and transport processes may generate such a landward transport of marine organic detritus. The likelihood that the nearshore will act as a sink for such material will be discussed later.

Relative Contributions--Riverine, Coastal, Marine

It is important to know the relative amounts of detritus supplied to the nearshore from each of the three potential sources. As indicated above, no estimates of the amounts of marine-derived materials supplied to the lagoons and bays are available. In terms of terrestrial sources, Schell (1978) and Cannon and Rawlinson (1978) have estimated that riverine and coastal erosional inputs are of the same order of magnitude.

Detritus Flux--Is the Nearshore Area a Trap?

We want to determine if and why shallow coastal environments are important for the maintenance of fish and bird populations that have been found to selectively use them. Because detritus is an important source of energy and nutrients fueling the food webs of fish and birds, it is important to determine whether the nearshore area selectively accumulates it (to the presumed advantage of fish and birds).

Coastal estuaries and lagoons function as detritus traps in many parts of the world. Meade (1969, 1972) believes that, at most, only about 10% of the riverborne suspended solids entering estuaries ever reach the sea. Drake (1976) states that the evidence for nearly perfect retention of fluvial suspensoids in many estuaries is incontestable. Hedgpeth (1957) maintains that the rate of deposition of land-derived detritus is far greater in lagoons and estuaries than in the open sea. Conomos and Peterson (1976) and Conomos (1979) found San Francisco Bay to be an effective sediment (and also presumably detritus) trap during normal river discharge conditions. The processes that regulate the behavior of detritus in coastal areas are reviewed below, with particular reference to the southern Beaufort Sea coast, to examine if and how the nearshore Beaufort is likely to collect detritus.

Detritus vs Inorganic Sediments

The behavioral relationships between organic suspensoids (detritus) and inorganic particles (sediments) are germane to this discussion for several interrelated reasons. First, a great deal more is known about sediment resuspension, transport and deposition than is known about detritus behavior. Second, organic materials appear to behave similarly to some inorganic sediments. Third, certain organic and inorganic materials may, by the process of flocculation, be bound together and thereby forced to share the same depositional fate.

Organic materials in the water are reported to have transport properties similar to those of inorganic fines (clay, silt). Generally, organic matter is associated with fines in depositional environments (Bordovskiiy 1965; Froelich et al. 1971). High organic carbon concentrations on continental shelves are generally encountered in mud (as opposed to sand) bottoms (Hatcher and Segar 1976). The reason for the co-deposition of organics with fines is presumed to be that the two behave similarly in water (Naidu 1978).

Suspended clay and organic particles may adhere to each other to form larger particles via the process of flocculation (Copeland et al. 1974; Pelletier 1975; Krone 1978). Co-deposition of the two thus becomes obligatory; flocculation may therefore augment the extent to which organics are to be found with inorganic fines in depositional sites. The influence of flocculation in determining the sites of deposition of detritus is discussed at greater length below.

Deposition of Terrigenous Detritus

The majority of eroded coastline materials and organic and inorganic materials carried by rivers are deposited in nearshore areas. It has been a common observation that particles suspended in streams discharging into coastal basins tend to settle there due to the sudden reduction of current speed (Hedgpeth 1957). The same is true for the Beaufort Coast. The larger, denser particles are dropped from suspension first, near the river mouths, and silt and clay are deposited farther away (Burrell et al. 1975). Most organic materials, similar to the inorganic fines, are probably not deposited immediately, but carried some distance prior to settling out. However, it is likely that the process of flocculation affects the depositional behavior of these clays and organics.

Flocculation is the physiochemical process whereby fine silt, clay, and organic particles in the water form aggregations because of the mutually attractive forces of their charged surfaces. Flocculation is minimal in waters having low salt concentrations (such as most streams), but increases markedly with salinity (Copeland and Dickons 1974; Krone 1978). For this reason its effects are most dramatic where particulate-rich fresh waters impinge upon high-salinity coastal waters. At present the data suggest that flocculation increases the settling rate in marine waters by up to one order of magnitude (Drake 1976).

Conditions under which rivers discharge the major portions of their organics into the nearshore Beaufort are ideal for extensive flocculation. The first several days of flood discharge in the spring may carry most of the annual detritus load (Cannon and Rawlinson 1978). At this time the nearshore lagoons are highly saline because of salt exclusion during the freezing of lagoon water. As the river waters spread seaward under the ice, with the highly saline waters beneath, the freshwater/saltwater interface becomes extensive. Walker (1974) notes that, although little mixing occurs initially across this interface, suspended material nevertheless settles through to the bottom. In the Canadian Beaufort, Pelletier (1975) noted that flocculation of clay and organic particles occurred extensively within and on the periphery of the Mackenzie River plume.

Flocculation also causes aggregation of organics introduced via coastal erosion, which occurs almost entirely during late summer and autumn storms. Although salinities of coastal waters at this time are normally lower than when river discharge begins, the turbulent mixing accompanying the storms acts to promote increased particle collision, which promotes flocculation (Krone 1978).

Although it is clear that there are higher deposition rates of terrigenous detritus in nearshore lagoons and bays than in offshore waters, a portion of the detritus is undoubtedly deposited seaward of lagoons and embayments. MacGinitie (1955) maintained that fresh vegetation and peat from freshwater discharge were deposited as far out to sea as 40 km (near Elson Lagoon). Barnes and Reimnitz (1972) and S. Johnson (pers. comm.) noted that some of the over-ice discharge from the Kuparuk River in spring proceeded seaward of Simpson Lagoon to discharge through the ice into marine waters.

Detritus Flux Between Marine and Nearshore Areas

Is the detritus that is preferentially deposited in nearshore areas from terrestrial sources gradually lost to the ocean, or is it supplemented by net landward transport of marine- and/or terrestrially-derived organics from the marine environment? The transport of organic matter under ice on the Beaufort Shelf is probably inconsequential (Drake 1977), so the main consideration is detritus movement during the open-water period.

Current patterns over the inner continental shelves of most areas of the world tend to concentrate resuspended shelf sediment (and presumably also detritus) in the nearshore zone; if estuaries are present, much of this material will be funneled into estuaries and deposited (Drake 1976). There is evidence that a major force contributing to this landward transport is the characteristic landward-flowing bottom currents (Conomos and Peterson 1976; Schubel and Carter 1976; Conomos 1979). Dyer (1978) shows that well-mixed estuaries have a turbidity maximum near the landward margin of the salt water intrusion at the bottom; this indicates that the mechanism driving salt water landward must also affect suspended sediment. Dyer found a net landward dispersion of sediment and correspondingly more sediment entrained during the flood (landward-moving) tide than on the ebb (seaward-moving) tide.

Whether Beaufort Sea marine sediments that are resuspended have a net landward transport is not known, but circumstantial evidence suggests that they do. Landward-flowing bottom currents (and probably associated sediment transport) caused by the predominant easterly winds and/or by characteristic estuarine-marine water exchange should be common, based on evidence provided by Hufford (1974), Herlinveaux and de Lange Boom (1975), Schell (1975), Wiseman and Short (1976), Barnes and Reimnitz (1977), and Barnes et al. (1977a). Shoreward-flowing bottom currents may not exist when winds are westerly, but coastal waters are generally held against the coast at these times (Wiseman and Short 1976) and extensive seaward transport is thereby prevented. However, C. Mungall (pers. comm.) cautions that westerly winds might also cause down-welling in nearshore areas, with a consequent seaward transport of bottom water and materials.

In summary, available evidence suggests that the coastal lagoons and bays may be sites to which marine-derived detritus (as well as terrestrially-derived organics) is delivered and deposited.

Effects of Topography

The topographic characteristics of nearshore environments may locally affect the ability of these environments to catch and hold detritus. Studies along the northeastern U.S. coast indicate that organic matter accumulates in depressions in the bottom (Hatcher and Segar 1976). Hedgpeth (1957) notes that troughs between submerged bars parallel to the shore may serve as traps for silt (and presumably detritus as well). Models show an entrapment of suspended material within shoreline irregularities, because of the predicted effects of these irregularities on current speed (Dyer 1978). It is presumed that topographic troughs and shoreline irregularities in the nearshore Beaufort would also cause detritus accumulation. E. Reimnitz (pers. comm.) found detritus accumulated landward (but not seaward) of terraces plowed parallel to shore by ice gouging. The lagoons themselves are troughs behind the barrier islands and spits; submerged spits and bars parallel to shore are characteristic features of the shallow coastal waters (Faas 1974; Short et al. 1974; Burrell et al. 1975). These emergent and submerged features undoubtedly enhance the effectiveness of the nearshore Beaufort as a detritus trap.

Depositional Evidence

The quantities of organic materials in sediment samples taken in various locations on the shelf may indicate recent as well as historical patterns of detritus deposition, since the non-living (detrital) organic material in such samples is likely to be the predominant portion of the total organic matter (Fox 1957). Unfortunately, normal methods of collecting sediments for analysis (grab, dredge, etc.) do not accurately measure recent deposits of detritus, which normally rest on top of the substrate. However, sampling effectiveness should be roughly comparable among sites where the same sampling device is used. Naidu and Mowatt (1975b) found the levels of organic carbon in sediments to be similar in Simpson Lagoon and adjacent Harrison Bay (0.79% and 0.77%, respectively), but lower (0.58%) in the nearby marine environment. In the Canadian Beaufort, Pelletier (1975) found higher organic carbon levels in sediments of deltaic and coastal areas than in the marine environment. Within the nearshore, Naidu (1978) found that organic carbon in sediments decreased in Simpson Lagoon from the mainland to the barrier islands. (The high levels near the mainland were postulated to be related to the nearness of these samples to the source of input, i.e., coastal erosion.) Because dredges were used for sampling in this case, it is not definite that these seaward decreases in carbon content reflect corresponding decreases in the surface deposits of detritus, although such is suspected.

Other depositional evidence for sites of detritus accumulation is based on the assumption that organic matter normally co-deposits with inorganic fines. Several investigators have described deposition sites for fine silts and clays in the nearshore Beaufort Sea; some have noted the co-deposition of these sediment sizes with organics. Naidu and Mowatt (1975b) point out that the sorting of sediments (and presumably also resuspension and transport of detritus) in the coastal waters of the Beaufort Sea occurs during storms. The ultimate depositional sites of fines are, therefore, the relatively "quiet" localities partially protected from wave action by a combination of topographic features and water depth. Emery and Stevenson (1957) note that mud substrates are usually characteristic of the quiet reaches of estuaries, where turbulence and current action are reduced. Burrell et al. (1975) and Naidu (1978) found an inverse correlation between mean particle size and water depth in Simpson Lagoon despite the fact that the Beaufort coastal sediments in general are poorly sorted (Naidu and Mowatt 1975a, b; Weller et al. 1978:106). This indicates that the central lagoon basin acts to selectively accumulate fine sediments (Naidu 1978), and perhaps (by inference) detritus.

Lewis and McDonald (1974) maintain that in the Canadian Beaufort Sea, three main sediment sinks exist along the southern coast--between Herschel Island and the mainland, in Phillips Bay, and in Shoalwater Bay. They present no evidence to imply that these are also detritus sinks, but the possibility may be presumed. No data documenting specific sites in the Alaskan Beaufort Sea as sediment or detritus sinks have been published.

GEOMORPHIC FEATURES AND THEIR EVOLUTION

The ecologically important geomorphic features along the Alaskan coast of the Beaufort Sea include:

1. The barrier islands which provide nesting sites for certain birds.
2. The island chains, which act as barriers to winds and waves and restrict water exchange between coastal and marine systems.
3. The inlets and passes, which connect lagoons with the ocean and with other lagoons, and allow transport of suspended materials and migration of aquatic organisms.
4. The shallow basins of lagoons, which promote rapid warming of coastal waters and provide ready access by birds to bottom-dwelling prey.

Two questions about these features must be answered before it will be possible to assess long-term consequences to fish and birds of some of man's activities.

1. What are the formative processes of the ecologically important features?
2. What time scales are involved in the natural formation and disappearance of these features?

Formative Processes

As noted above, some of the geomorphic features along the Beaufort Sea coast are directly or indirectly important to fish and birds.

The processes that have given rise to these features must be understood in order to evaluate the long-term consequences of development activities that would change these features. Only by evaluating these formative processes can we predict whether the changes wrought by development are likely to be naturally mended. For example, if island materials are now supplied by processes that will no longer function after some development activity, or if islands were orginally formed by processes that are not now functioning, then removal of islands or portions of islands may be an irreversible change.

Barrier Islands, Lagoons and Estuaries--General Considerations

The formative mechanisms for coastal barrier islands and their associated estuaries and lagoons have been the focus of controversy over the past century (Schwartz 1973; Wanless 1976). Recent evidence suggests that several processes may act jointly or independently to generate barrier islands in various areas of the world (Zeigler 1959; Otovos 1970; Schwartz 1971). These processes are closely tied to sea level fluctuations (Gill 1967).

Most coastal geologists agree that there has been a general worldwide rise in sea level since the last glaciation (LeBlanc and Hodgson 1959; Shepard 1960; Schwartz 1965; Godfrey 1976; Riggs 1976; Wanless 1976). Many of these workers think that the general rise is continuing, although some (Leontyev 1965; Leontyev and Nikiforov 1965) maintain that a drop in sea level occurred during a brief interlude several thousand years ago. A few investigators (LeBlanc and Hodgson 1959) have found local evidence that the post-glacial rise stopped a few thousand years ago and that the sea level has since remained constant.

Assuming a continued gradual rise in sea level, we will consider three mechanisms that have been proposed for the formation of present-day barriers and the shallow lagoons behind them: (1) the building of barriers by sand thrown up from the continental shelf, (2) the elongation of sand spits built from headlands by longshore drift, and their eventual breaching by tidal action, and (3) the gradual submergence of low-lying coastal areas behind topographic highs (Schwartz 1971; Wanless 1976).

Evidence from some coasts indicates that barrier islands have been formed and/or enlarged by the accretion of submerged shelf materials onto nearshore submarine or emergent features (Fig. 5). LeBlanc and Hodgson (1959) and Shepard (1960) found evidence that materials for many of the barriers along the Gulf of Mexico were derived from shelf sediments that presumably built upon existing emergent islands, or upon submerged bars. The latter are characteristic of shallows immediately off sandy beaches (Hedgpeth 1957). Otvos (1970), working in the same area, and Leontyev (1965), studying barriers in the U.S.S.R., reached similar conclusions about barrier island formation.

Pierce and Colquhoun (1971) doubted that emergent barriers could be built by wave action from submerged bars, particularly at a time when the sea level is rising. They quote Kuelegan (1948), King (1960:337) and McKee and Sterrett (1960) to the effect that breaking orbital waves have questionable ability, in most circumstances, to build an emergent barrier upon a submerged feature. Submarine bars are built by waves but, instead of emerging, the bars usually migrate landward and eventually become part of a pre-existing feature. Under these assumptions, the generation of a barrier by shelf sediments thrown up by waves appears to depend on the existence of an already-emergent feature upon which to build. Regardless of whether submerged bars can emerge during a rise in sea level, once emergent barriers exist, they commonly grow by upward aggradation and remain emergent in spite of a rise in sea level (Shepard 1960).

The generation of sand spits from the mainland or from existing islands is sometimes implicated in barrier island and lagoon formation (Fig. 5). These barrier spits are nourished by longshore transport of materials (usually sand) derived from erosion of headlands or from river discharge (Pierce and Colquhoun 1970; Wanless 1976). Eventually, segments of the spits become islands as the spits are breached by wave action during storms. Examples of barriers formed in this way may be seen in such locations as the Atlantic coast of the United States (Pierce and Colquhoun 1970) and coastal Australia (Bird 1973).

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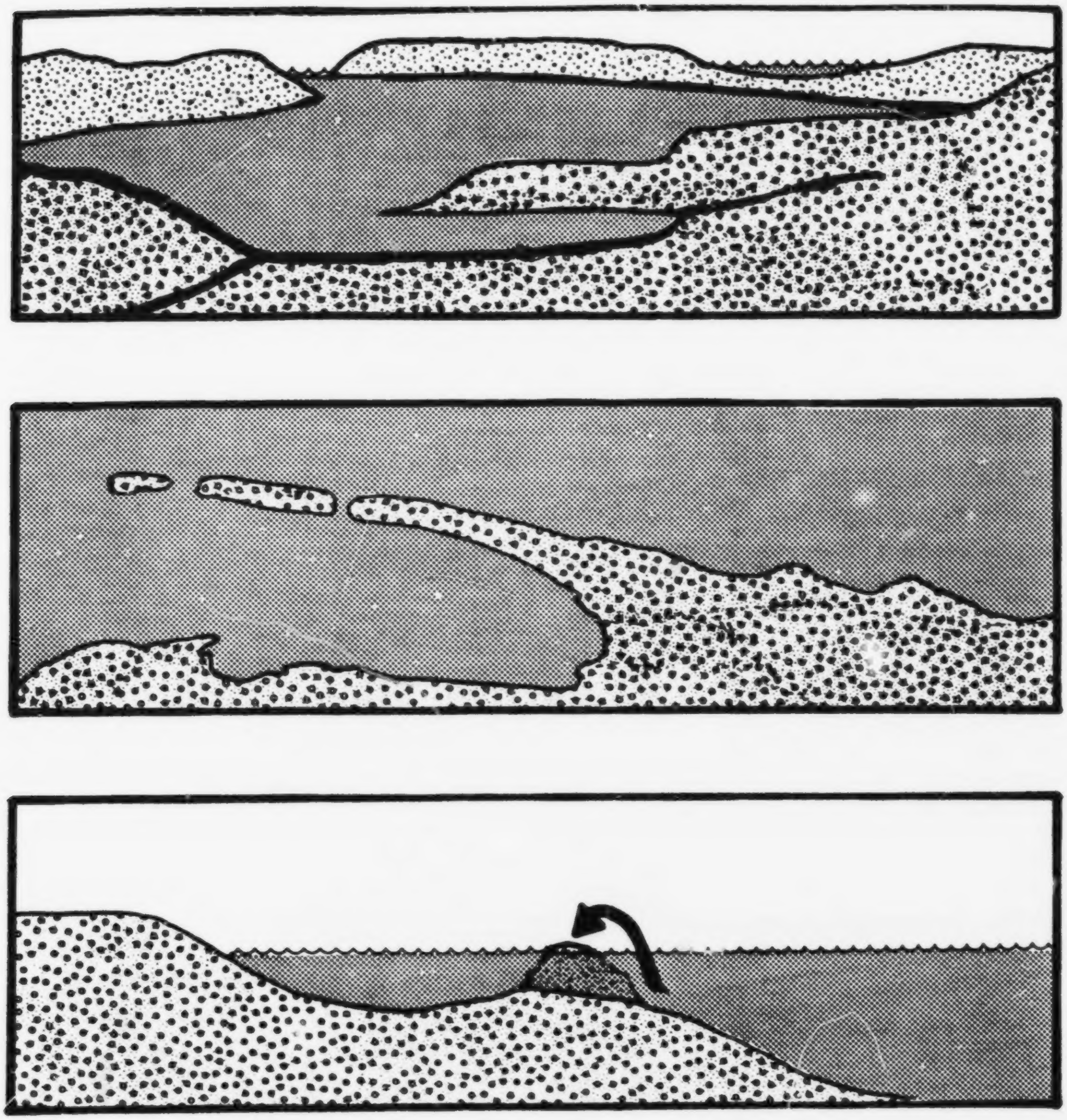

Figure 5. Three general mechanisms have been proposed as formative processes for barrier islands: inundation of coastal lowlands behind beach ridges (top); breaching of spits built by longshore drift (middle); and deposition of sand thrown up from the continental shelf (bottom).

Isolation of coastal headlands by inundation of coastal lowlands behind the headlands may be an important formative mechanism for barrier systems in some areas (Fig. 5). Coastal subsidence as a consequence of the rising sea level is the ultimate causative phenomenon. That sea level rise caused coastal lowland submergence was noted early (McGee 1890) along the east coast of the United States. Zeigler (1959) postulated that barrier islands and associated estuaries along the southeastern United States originated by coastal submergence. Hoyt (1967) precipitated more recent controversy in proposing that barrier islands form by gradual submergence of coastal lowlands behind beach-dune ridges (Wanless 1976). Since then, coastal submergence and consequent isolation of mainland features have been commonly postulated as generating mechanisms for island-lagoon systems along the coast of the southeastern United States (Pierce and Colquhoun 1970; Godfrey 1976).

It is now conceded that a combination of mechanisms can form and maintain barrier/lagoon systems (Ziegler 1959; Schwartz 1971). Pierce and Colquhoun (1970) propose that both primary barriers (built on or derived from relict mainland features) and secondary barriers (built from spit extensions of mainland or primary barriers) are common along the North Carolina coast. They maintain that the two different formative processes are not mutually exclusive, but commonly interact. Zeigler (1959) also recognized along the South Carolina coast both mainland-derived emergent features ("erosion remnant" islands) and barriers formed from spit accretion off headlands and islands ("beach-ridge" islands). He proposed that the former were built upon relict features and the latter accreted over submarine deposits by longshore transport and deposition of sediments.

Barrier Islands and Lagoons--Beaufort Sea

There also appears to be a continuing rise in sea level relative to coastal substrates along the southern coast of the Beaufort Sea. Weller et al. (1978:103, 105), using data compiled by D.M. Hopkins, showed that 20,000 years ago the surface of the Beaufort Sea was about 80 m below its present level. The increase in sea level, then, has averaged about 40 cm/century for this period. Because of this rise in sea level, the process dominating the formation of barrier island-lagoon systems is probably marine impingement into coastal regions. Two types of barriers (relict and constructional) appear to have been formed as a consequence.

Relict Barriers. It is generally accepted that those Beaufort Sea coastal islands capped with tundra vegetation and peat are remnant mainland features (Cannon and Rawlinson 1978; Weller et al. 1978:127). The biological evidence of this is clear--islands have a vegetative covering that is identical with that of the mainland and that overlies undisturbed peat deposits several thousand years old. The geological evidence is also unmistakeable; Cannon and Rawlinson (1978) show that the lake basins on the islands are similar in form and orientation to mainland lake basins and that mainland and island substrates have similar stratigraphies and lithologies.

A feature that has promoted the isolation of coastal bluffs and the associated formation of lagoons is the abundance of lakes in the relatively flat landscape of the coastal plain. Evidence that these lakes have coalesced behind coastal highs, thus hastening the formation of lagoons, has been presented by Faas (1974) and Cannon and Rawlinson (1978) for the Alaskan Beaufort and by Lewis and Forbes (1975:4) for the Canadian Beaufort.

Constructional Barriers. Most of the coastal barrier islands are surfaced with sand and gravel and are, according to conventional definition, constructional (Weller et al. 1978:127), notwithstanding that their constituent gravel and sand may have come from relict features (Naidu 1978). The knowledge that they are constructional (at least in part) is insufficient for evaluation of the potential consequences of development; the constructional processes and source materials must also be known.

Particles larger than sand (gravels, boulders) comprise a large portion of the constructional materials of Beaufort Sea barrier islands. These gravels are thought to have been very local in origin, because wave and current energies capable of transporting them from elsewhere do not presently exist along the Beaufort coast (Naidu and Mowatt 1975a; Cannon and Rawlinson 1978). Naidu and Mowatt (1974) postulated that some of the large boulders found sparingly on these barriers might have been ice-rafted from elsewhere, but Cannon and Rawlinson (1978) and Weller et al. (1978:111) disagreed with that view. Cannon and Rawlinson (1978) believed the gravel and boulders to be deposits from eroded remnant islands.

The specific mechanisms and magnitudes of transport of the gravel are not completely known. Faas (1974), Reimnitz et al. (1977), Cannon and Rawlinson (1978), and Weller et al. (1978:124) think that they are transported very short distances, and are only locally reworked by ice shove and wave action. Weller et al. (1978:124, 129) imply that transport of gravel may be restricted to the island where the gravel originated, especially if islands are separated by relatively deep inlets. Rex (1964) working in the western Beaufort near Barrow, and Lewis and Forbes (1975) working in the eastern Beaufort, found that gravels may be transported considerable distances along spits. Nevertheless there is general agreement that present-day transport of gravel on the Beaufort Sea shelf by natural processes is very limited (Reimnitz et al. 1977; Weller et al. 1978:129; and others).

Sand-sized and finer sediments may be moved through the nearshore system by longshore transport and thereby supplied to barrier islands and spits from relatively distant sources (Lewis and Forbes 1975:3; Cannon and Rawlinson 1978; Naidu 1978). (Of these sub-gravel-sized particles, those comprising constructional spits and barriers are mostly sand, so silts and clays are not of significant concern.) The primary sources of sand for barrier and spit accretion along the coast of the Beaufort Sea are presumed to be river discharge and erosion of coastal headlands; landward transport of continental shelf sands has not been postulated to be significant. As might be suspected, sand discharged into the nearshore by rivers appears to settle near the deltas, whereas clays and silts tend to travel farther (Burrell et al. 1975). Similarly, sand released from eroded coastal headlands is initially deposited near its source (Schwartz 1965).

Once the sand is deposited, it is not easily resuspended by waves and transported by currents unless it remains in very shallow water (Burrell et al. 1975; Swift 1976; Naidu 1978). The fact that sand at depth is not readily resuspended and transported suggests that a shallow-water "corridor" must exist between a sand source (e.g., river depositional site, mainland or island depot) and an emergent feature in order for the feature to be significantly nourished by sand from such sources. Maximum depths at which sand is readily resuspended and transported along low-energy coasts such as along the southern Beaufort Sea are not known. However, sedimentologists working along the Beaufort Sea coast (e.g., Burrell et al. 1975; Naidu 1978) have found that lagoons with depths of only a few meters selectively accumulate fine-grained (silt, clay) particles, suggesting that sand from terrestrial sources is not readily transported into and across such depths to the barriers beyond. This is supported by observations that most sand transport from mainlands and barriers seems to be along emergent or slightly submerged spits extending from headlands or existing islands (c.f. Pierce and Colquhoun 1970; Burrell et al. 1975; Wanless 1976), or along the beaches of chains of emergent barriers. Even the transport of sand along barrier chains may be hindered by the presence of inlets between islands (Weller et al. 1978:129).

In the final analysis, then, most constructional barrier islands along the Beaufort Sea coast are probably relict features that have been eroded and reshaped by wave action and ice push. Their large particles were probably dropped in place as the islands eroded, and are not being currently supplemented from elsewhere. The islands may be nourished by sands from more distant river discharges or erosion of coastal headlands if they are separated from such sand sources by relatively shallow depths, but deep lagoons and inlets may partially or completely block such supplies of sand.

Whether sand from the deeper marine areas of the continental shelf also accretes in significant quantities to the nearshore barriers is not known, but such has not been postulated to be the case.

Time Scales of Change

The impacts of development activities on biological communities persist only when the habitat changes exceed the capacities of organisms within the communities to adjust. If the development activities do not persist, most (but not all, see Holling 1978:30-32) ecological impacts are temporary in the sense that populations can resume their original status and function once the habitat is "repaired". Thus an important question in assessing long-term ecological impacts is "How long will habitat changes caused by man persist?"

This question is especially important in assessing the impacts of landscape changes in coastal regions of the Beaufort Sea because the effectiveness of physical processes in molding some geomorphic substrates suggests that some changes in these substrates would eventually be mended by natural forces. The critical questions relate to how fast the natural changes will obscure the man-caused changes.

In this section we will address rates of natural geomorphic change in the barrier islands, the lagoon basins, and the mainland coasts, with a view to estimating the permanence of man-caused changes in these features. It should be remembered that natural changes in all these features will be influenced greatly by coastal subsidence.

Barrier Islands

Storm surge events rapidly erode the tundra and peat covers of mainland relict islands. Cannon and Rawlinson (1978) estimated that the margins of tundra caps on islands enclosing Simpson Lagoon erode at an average rate of 1.6 m per year. They also estimated that these islands will retain their tundra/peat caps for lengths of time varying between 35 and 270 years (depending on island size), given the present rates of erosion.

Likewise, both sand-and-gravel islands and the sand-and-gravel portions of tundra-capped islands change shape and move rapidly. Sand and gravel from the eastward and seaward extremes of islands appear to be eroded and transported to accrete to the westward and landward portions of the islands; consequently the direction of island migration is predominantly westward (in the direction of the dominant longshore transport) and southward (landward). Islands migrate at annual rates estimated variously to be 6-25 m (Short et al. 1974), 6-72 m (Reimnitz et al. 1977), and 13-30 m westward and 3-7 m landward (Weller et al. 1978:12).

The tenure of Beaufort Sea barrier islands as emergent features is not known. Presumably it must be a matter of centuries, since all the major islands in existence at the time the arctic coastal islands were first mapped in the early 20th century are still in existence, and no major new islands have formed since then. Reimnitz et al. (1977) state that Cross Island northeast of Prudhoe Bay has apparently not changed greatly in emergent area since it was mapped by the U.S. Geological Survey in the early 1900's (Leffingwell 1919). Considering that most of the islands presently extend at least 1-2 m above sea level, it would take several centuries for them to be submerged at the estimated present rate of sea level rise if no erosional degradation in height occurred in the interim. Evidence from other areas suggests that such degradation would not occur, for emergent features frequently tend to build upon themselves to remain emergent as the sea rises (Shepard 1960).

Lagoon Basins

Since the lagoons depend on the existence of barriers, a lagoon and its barrier islands have similar durations. However, during the lifetime of a barrier island-lagoon system, the geomorphic boundaries of lagoons may change in important ways. Lagoon depth, inlet characteristics, and lateral extent are all ecologically significant attributes that may change with time.

Change in depth of nearshore waters is a function of the balance between sediment deposition (which causes shoaling) and subsidence and/or sediment removal (which deepens coastal basins). Emery and Stevenson (1957) and Hedgpeth (1957) observed that deposition (largely of stream-derived sediments) caused depths of Texas bays to decrease by about 23 cm in 65 years, despite a general coastal subsidence of about 30 cm during the same period. Schwartz (1965), in a laboratory study of rise in sea level and shore erosion, suggested that the rise of nearshore bottoms simply as a result of deposition of beach-eroded materials should equal the rise in sea level, thus maintaining a constant nearshore water depth despite regional subsidence.

In sheltered waters along the Beaufort coast of Alaska, measured net sedimentation rates are 5 cm/century off the Colville delta, 10 cm/century in many nearshore areas (both inside and outside barrier islands), and as much as 60 cm/century in Prudhoe Bay (Weller et al. 1978:106). These sedimentation rates are of the same order of magnitude as the average 40 cm/century rate of increase in sea level estimated for the last several thousand years (calculated from data of Weller et al. 1978:105). The implications are that regional subsidence may compensate for much or all of the potential shoaling caused by deposition, and that, as a consequence, lagoon depths may remain fairly constant for long periods. However, since the estimates of both subsidence and deposition rates are very imprecise, the rate of change in water depths in coastal regions of the Beaufort Sea is uncertain.

Inlet characteristics and locations, as we have seen, are primarily a function of the hydraulic forces impinging on a barrier island chain (Emery and Stevenson 1957; Riggs 1976). Short-term changes, particularly in inlet shape and size, may be very rapid in direct response to hydraulic pressures, but over the long term, inlets with the same general characteristics will recur to accommodate discharge forced by the regional oceanographic circulation patterns. Therefore, as the depth and lateral conformity of a lagoon change with time, inlets will correspondingly change in size and location. Weller et al. (1978:129) imply that inlets in Beaufort Sea barrier island chains migrate westward with the individual islands. However, inlets opposite river mouths (for example, Egg Island Channel off the Kuparuk River delta) must remain in the same general locality to accommodate the annual river discharge.

Weller et al. (1978:127) report that constructional islands along the Beaufort coast migrate landward at an annual rate of about 3-7 m. This rate is similar to, and in the same direction as, the coastal erosion rates estimated by various researchers (see following section). Given, then, that both the island/lagoon margins and the mainland/lagoon margins are moving southward at similar rates, lagoon width should remain fairly constant for long periods.

Mainland Coasts

As noted earlier, the mainland along the Beaufort Sea coast is receding, eroded mostly by storm surge action. There is extreme short-term variability in erosion rates because erosion is significant only during storms. Estimates of annual rates of coastal recession vary. Schell (1975) calculated annual rates of 1.4 m/year over 22-23 years for a stretch of mainland bordering Simpson Lagoon, and Cannon and Rawlinson (1978) estimated retreat rates of about 1.2 m/year for the mainland in the Simpson Lagoon area. Hume and Schalk (1967) reported a beach retreat of about 9 m during the course of one storm near Barrow, and Leffingwell (1919) reported short-term erosion rates of up to 30 m/year at Drew Point and Cape Simpson. Lewis and Forbes (1975:3) report sea cliff retreat of up to 90 m in 16-18 years along the Canadian Beaufort coast. Weller et al. (1978:126) estimate that coastal retreat averages 1 m/year in the Canadian Beaufort west of the MacKenzie Delta, 1.6 m/year in the Alaskan Beaufort east of the Colville Delta, and 4.7 m/year in the Alaskan Beaufort west of the Colville Delta.

CONCLUSIONS

A summary of important conclusions follows.

In summer along the Beaufort Sea coast, prevailing wind regimes cause water to rapidly exchange between adjacent coastal water bodies. Exchange between coastal and offshore waters is, on the other hand, sufficiently restricted that the two systems remain measurably different in their temperatures and salinities, and presumably in other attributes as well. In winter, coastal circulation and exchange rates are much reduced from those of summer.

The water exchange that occurs between the relatively warm and brackish nearshore waters and the colder, more saline ocean waters is probably dominated near river mouths by an exchange pattern characteristic of many estuarine areas--landward intrusion of ocean water near the bottom and seaward movement of nearshore water at the surface. This process may commonly be augmented by coastal upwelling along the coast. The rates of these exchanges are retarded by barrier island chains and by the natural tendency for the wind-driven currents to move parallel, rather than perpendicular, to the coast.

Currents near the bottom are more important in transporting ecologically significant materials than are currents higher in the water column. Existing data suggest that there is a dominant landward component in the bottom currents in summer that may promote net landward delivery of materials and organisms entrained in the lower part of the water-column.

The amounts of detritus delivered to the nearshore waters by river discharge and by coastal erosion appears to be similar; amounts delivered from offshore environments have not been quantified. Several lines of evidence strongly suggest that nearshore basins behind barrier islands, submerged bars, and other prominences are traps for detritus from all three sources.

Major barrier islands along the Beaufort Sea coast are of two related kinds--relict mainland features and constructional barriers built upon or from relict features. They were originally formed as the sea rose and inundated areas behind coastal highs. Most of these islands are apparently not presently being nourished significantly by materials transported from distant sources.

Lateral shifts in coastal landforms are rapid--margins of coasts, islands, and lagoon basins annually move several meters landward and/or westward. Large-scale vertical changes in topographic features are much slower, and seem to be controlled over the long-term by the tendency of the rising sea to inundate features and the opposing tendency of bottoms of lagoon basins and surfaces of islands to rise because sand and silt accrete to them. Tens of centuries may pass before the sea drowns the existing barrier island-lagoon systems and intrudes landward to form new systems from lake beds and other low places behind coastal ridges.

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TABLE OF CONTENTS

Page

SUMMARY 113
  Migration Studies 113
  Nesting Studies 114
  Molting and Staging Studies 114
  Feeding Studies 115
  Disturbance Studies 116
  Conclusions 116
ACKNOWLEDGEMENTS 117
SPECIAL NOTE 117
INTRODUCTION 118
  General Nature and Scope of Study 119
  Specific Objectives 119
  Relevance to Impact Assessment 120
CURRENT STATE OF KNOWLEDGE IN THE BEAUFORT SEA AREA 121
STUDY AREA 123
METHODS AND RATIONALE OF DATA COLLECTION 129
  Migration Studies 129
    Spring Migration 130
    Mid-Summer Molt Migration 133
    Fall Migration 134
  Nesting Studies 134
    Survey Methods 135
  Molting and Pre-Migratory Staging Studies 136
    Aerial Surveys During 1977 and 1978 137
    Shoreline Transects 140
  Feeding Studies 141
    Collections of Birds and Habitat Samples 142
    Laboratory Techniques 145
MIGRATION STUDIES 148
  Results 148
    Spring Migration 148
    Molt Migration 182
    Fall Migration 192

TABLE OF CONTENTS (cont'd)

Page

Discussion 205

Spring Migration 205
Molt Migration 215
Fall Migration 220

NESTING STUDIES 224

Results 224

Discussion 230

MOLTING 236

Results 236

Oldsquaw Pre-Molt Period 236
Oldsquaw Molt Period-Males 139
Oldsquaw Molt Period-Females 256
Oldsquaw Post-Molt Period 260

Discussion 268

Pre-Molt Period 268
Molt Period 270
Post-Molt Period 276
Oldsquaws in Areas Other Than Simpson Lagoon 279

PREMIGRATORY STAGING 286

Results 286

Shorebirds 286
Arctic Tern 293
Glaucous Gull 299

Discussion 302

Phalaropes 305
Glaucous Gull 309
Arctic Tern and Sabine's Gull 310

FEEDING ECOLOGY 311

Results 311

Oldsquaw 311
Phalaropes 320
Glaucous Gull 327

Discussion 329

Oldsquaw Feeding Ecology 329
Phalarope Feeding Ecology 336
Gull and Tern Feeding Ecology 339
The Trophic Role of Birds in an Arctic Marine Lagoon System 341

TABLE OF CONTENTS (cont'd)

Page

ECOSYSTEM SIGNIFICANCE AND IMPACT PREDICTIONS 346
CONCLUSIONS 353
LITERATURE CITED 355
APPENDICES 374

SUMMARY

In 1976, LGL initiated an interdisciplinary, process-oriented study of a barrier island-lagoon ecosystem on Alaska's Beaufort Sea coast. The general scope of the ornithological components of this study, which was sited primarily in the Simpson Lagoon area, was to characterize the use of nearshore habitats by birds and to clarify those critical feeding and habitat dependencies that development is likely to affect either directly, or indirectly via alteration of ecosystem processes.

The research program addresses four ecosystem uses/dependencies of birds--for migration, breeding, feeding and staging-molting. These uses are evaluated as they relate to barrier island-lagoon habitats and predicted development alterations of habitats.

Migration Studies

Spring migration during 1977 and 1978 (late May to mid-June) was eastward over a broad front; major bird groups involved were loons, brant, pintails, oldsquaws, eiders, glaucous gulls and jaegers. After river water had overflowed onto the lagoon ice in early June, a few loons and some waterfowl landed on the overflow water.

The westward molt migration by male seaducks included two peaks--movement of oldsquaws during late June and early July, prior to breakup in the lagoon or in the sea, and a modest movement of common and king eiders through the study area, mostly during the third and fourth weeks of July after the lagoon and sea ice had retreated. In addition, male surf scoters flew west through the Simpson Lagoon area in July 1978. Oldsquaws made moderate use of shoreleads in lagoons and light use of leads in the ice in mid-lagoon during the course of their molt migration; eiders made light use of lagoon habitats during the westward molt migration.

The fall migration by birds out of the Simpson Lagoon area was more protracted than either the spring or molt migration. Most oldsquaws and glaucous gulls had not begun their fall migration out of the study area when the field season was terminated on 25 September 1977 and 1978. A westward movement of adult and juvenile arctic terns occurred along the barrier islands during the third and fourth weeks of August, at which time they congregated at gaps between the islands and along the spits and sandbars where food was more readily available to this species. A major movement of black brant occurred along the mainland coast in the last days of August and the early days of September during 1977 and in the second and third weeks of August during 1978. A westward movement of loons through the lagoon occurred in late August and early September of 1977 and 1978.

Nesting Studies

During 1977, arctic foxes preyed heavily on eggs of birds which nested on the barrier islands, and (presumably because of the predation) densities of successful nests were relatively low. Indications were that in the absence of arctic foxes on gravel islands, the nesting potential for traditionally island-nesting species was high.

During 1978, arctic foxes were absent from the barrier islands. Although the density of tundra nesting birds remained low, those species associated with the gravel islands were more productive than during the preceding year when foxes were present.

Molting and Staging Studies

An estimated 30,000 to 51,000 male oldsquaws may concentrate in the lagoon between mid-July and mid-August to molt. Few molting oldsquaws occur seaward of the barrier islands; however, post molting male oldsquaws may move to offshore locations during late August and early September. An estimated 33,000 to 106,000 oldsquaws, primarily females and juveniles, may occur in the Simpson Lagoon study area during late September after tundra wetlands freeze and are unavailable to these birds.

Juvenile northern and red phalaropes arrived to feed along the shorelines of the barrier islands and mainland both in 1977 and 1978 during August; thousands of individuals concentrated along the beaches of the barrier islands during the mid and late parts of August.

Glaucous gulls in the study area were most intensively studied during 1977; they were associated with shorelines and their distribution appeared to be related to the availability of food. During September 1977 and 1978 the number of glaucous gulls increased dramatically in the area; during 1977 they were most abundant along the seaward beaches of the barrier islands, where food (hyperiid amphipods) was concentrated along sections of the shoreline.

Feeding Studies

During both 1977 and 1978 oldsquaws ate primarily mysids and amphipods, and to a lesser extent, bivalves. They ate largely the kinds of foods that were most available; during 1977 their diet was very similar to that of the arctic cisco, the most common coregonid fish in the lagoon.

During both 1977 and 1978 oldsquaws were fattest from mid-July to mid-August, the period of molt. Their fat reserves declined thereafter, which suggests that subcutaneous fat may play an important role during the molt period (e.g., for insulation and/or to satisfy maintenance energy requirements) and that this fat may be utilized after the molt to help meet the energy demands associated with feather replacement. Throughout the summers of both 1977 and 1978 the standing stocks of epibenthos used as food by oldsquaws remained at least one order of magnitude greater than the estimated per-day food requirement of the birds.

During 1977, glaucous gulls in the study area fed exclusively along shorelines and ate mainly isopods, amphipods, small fish and small birds. The relative proportions of these organisms in the diet bore little resemblance to their proportions at the locations where glaucous gulls were collected. Feeding overlap studies indicated that the diet of glaucous gulls was more similar to that of the four-horned sculpin than to that of any other common vertebrate studied. The highest densities of glaucous gulls were recorded along the beaches of the barrier islands during the third week of September in both 1977 and 1978. At this time during 1977, glaucous gulls were feeding on hyperiid amphipods that were concentrated along sections of the seaward shorelines of the barrier islands.

Both northern and red phalaropes are specialized shoreline feeders. Phalaropes concentrating on coastal shorelines in August of 1977 and 1978 ate primarily copepods, small amphipods and small mysids. The proportions of these organisms in the diet of phalaropes during 1977 were similar to the proportions of these taxa found in their feeding habitats along shorelines. During 1978, phalaropes selectively preyed on small amphipods which in shoreline feeding habitats were much less abundant than mysids and slightly less abundant than copepods. During 1977 and 1978, the diets of red and northern phalaropes were very similar to each other. During 1977, the diets of phalaropes collectively were similar to diets of arctic char and least cisco.

Disturbance Studies

Data from other studies coupled with observations made during the course of this study showed that the vulnerability of birds to disturbance varies among species, habitats, and type of bird activity.

Table 60 gives a sensitivity/vulnerability matrix of important avian species and their habitats, with notes about the periods when each species is most vulnerable to development-related activities affecting each habitat.

Conclusions

General conclusions were that

1. Bird utilization of lagoon areas was negligible while these areas remained frozen in spring and early summer; potential impacts of development are, therefore, probably low at this time except for those activities that would create open water attractive to birds.
2. Shoreleads were used moderately by birds before the nearshore area became ice-free.
3. Species that nest mainly on barrier islands nested at higher densities on the gravel/sand islands than on the tundra-covered barrier islands. Species nesting on the latter are also widespread on the mainland tundra. If development activities are restricted to tundra sites on the barrier islands, then disturbance to island-specialist species should be minimal.
4. Shorebirds (primarily phalaropes) that stage in barrier island-lagoon habitats during August are most heavily concentrated along the seaward shorelines of the barrier islands.
5. Molting and post-molting oldsquaws are abundant and are highly concentrated at several barrier island-lagoon sites in and to the east of Simpson Lagoon. In general, the shallow and/or turbid waters directly under the influence of the Colville River, west of Simpson Lagoon in Harrison Bay, supported primarily glaucous gulls and only a few oldsquaws.

6. Feeding studies indicated that oldsquaws preyed most heavily on larger individuals of the three major taxa of invertebrates that were most abundant in lagoon epibenthic habitats, and that oldsquaws preyed most effectively in areas where densities of invertebrates were highest.
7. Heaviest use of neashore barrier island-lagoon areas by birds occurred during the open-water season--late July through August and September. Primary use of the area at this time was by post-breeding oldsquaws and staging shorebirds. Feeding activity in the area was intensive by all these birds. Potential impacts of development, therefore, would be most serious during this open-water season.

ACKNOWLEDGEMENTS

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SPECIAL NOTE

This is the third and final report of our investigations of the Jones Islands-Simpson Lagoon system. Many of the data presented in this report also have been presented in two earlier reports (Johnson 1978, 1979). Because of refinements and revisions in the analytical procedures, numbers presented in the text, tables and figures of this final report may differ from (and supersede) those in the earlier two versions.

INTRODUCTION

The Alaskan Beaufort Sea, especially its coastal lagoons and barrier islands, is an important area to many species of water-associated birds. During portions of the year, significant fractions of the total North American populations of a number of species are present in the nearshore waters of the Beaufort Sea (Johnson et al. 1975). These include the following: yellow-billed loon, brant ($<10^5$)*, oldsquaw (10^6), common ($>10^5$) and king (10^6) eiders; glaucous, Sabine's and Ross' gulls; arctic terns; and red and northern phalaropes. Some of these birds occur in the coastal Beaufort Sea area only during migration, but others also nest, molt, feed and accumulate fat reserves there (Johnson et al. 1975).

General Nature and Scope of Study

In 1976, LGL scientists initiated an interdisciplinary process-oriented study of a barrier island-lagoon ecosystem on Alaska's Beaufort Sea coast. The general scope of the ornithological portion of this study, which was sited largely in the Simpson Lagoon area, was to

1. assess the importance to birds of barrier island-lagoon habitats in the Beaufort Sea,
2. determine the degree and nature of dependencies by birds on these habitats, and
3. clarify those critical feeding and habitat dependencies that development is likely to affect either directly or indirectly via alterations of ecosystem processes.

Specific Objectives

The research program addresses each of four ecosystem uses or dependencies of birds--migration, breeding, molting and staging, and feeding. These uses are evaluated as they relate to barrier island-lagoon habitats and predicted development alterations of habitats with these objectives:

1. Determine the timing, routes, numbers and major species involved in the spring migration, molt migration and fall migration of birds through a barrier island-lagoon system.
2. Identify the economically or aesthetically important (key) species of birds in the major habitat types present in the barrier island-lagoon system, obtain quantitative estimates of their seasonal abundance in each habitat type, and determine the nature of their utilization of these habitats.
3. Obtain quantitative estimates of the density, nesting success, and major predators of birds in the typical barrier island-lagoon habitats.
4. Determine the major food organisms consumed by the key bird species during periods of their peak abundance in a barrier island-lagoon system.
5. Determine the trophic relationships between the key species of birds, their food organisms and their feeding habitats: e.g., Do key bird species select particular food organisms or do they simply eat in accordance with the relative availability of the food organisms? Does cropping by birds have a significant effect on food availability? Do different species of birds (and fish) depend on the same food organisms?

---

*Estimated order of magnitude of numbers of birds entering the Beaufort Sea annually (Thompson and Person 1963; Johnson 1971; Bellrose 1976; Timson 1976).

Relevance to Impact Assessment

Plans for the development of petroleum resources in the coastal area of the Alaskan Beaufort Sea are proceeding rapidly. Activities affecting the coastal barrier islands and accompanying lagoon systems play a prominent role in the various development scenarios presented by the petroleum industry (Weller et al. 1978). Federal and state authorities have expressed the desire that development proceed with minimum disturbance to bird populations that are of concern to society because of their aesthetic, sport or subsistence value.

Industrial activity following petroleum leasing of nearshore waters may potentially affect birds in two major ways:

1. By imposing direct mortality or stress (e.g., oiling of birds, disturbance caused by human activities such as aircraft overflights, destruction of nesting habitat, introduction or attraction of predators).
2. By interrupting key physical and biological processes (e.g., coastal erosion, water circulation, nutrient and invertebrate production and cycling, etc.) that currently enable birds to successfully use the area during migration and for breeding, feeding, staging and/or molting.

CURRENT STATE OF KNOWLEDGE IN THE BEAUFORT SEA AREA

In general, prior to the initiation of the present barrier island-lagoon studies, little information was available regarding the spatial and temporal patterns of abundance and distribution of birds in the various barrier island-lagoon habitats. No information existed regarding the feeding ecology of key bird species in relation to their prey in barrier island-lagoon habitats, nor regarding the effects of predation (by foxes) on birds nesting on barrier islands. Prior to this study little quantitative information existed regarding the densities on the barrier islands of tundra-nesting birds, relative to densities of birds that typically nest on gravel/sand substrates and on the adjacent mainland tundra.

Knowledge, as of 1975, of birds found in the Beaufort Sea area was reviewed by Johnson et al. (1975). Searing et al. (1975) and Richardson et al. (1975) present results of aerial surveys of sea-associated birds in the Canadian Beaufort Sea during 1972 and 1974, and in 1975, respectively. Barry (1976a) has presented a brief summary of all available information on seabirds found in the Canadian Beaufort Sea. Richardson et al. (1975) and Johnson et al. (1975) presented detailed information on the spring migration of birds along a portion of the Beaufort Sea coastline in the Yukon Territory and northeastern Alaska.

Several published accounts describe the birds in the immediate vicinity of the Jones Islands-Simpson Lagoon area. Hall (1975; unpublished 1972 data) has provided an annotated list of the birds seen near Oliktok Point and in Simpson Lagoon from 12 June to 23 August 1971 and intermittently from 11 May to 27 November 1972. Gavin (1976) reported on water bird production along most of the barrier islands in the vicinity of Prudhoe Bay, including the Jones Islands, for the 6-year period 1970 through 1975. Divoky (1978b) conducted ground and aerial surveys of nesting birds along all of the barrier islands in the Alaskan Beaufort Sea during 1976, including the Jones Islands; he also conducted two aerial surveys of the Simpson Lagoon area during 1976. During 1977, Divoky (1978a) conducted opportunistic shipboard surveys of birds in Simpson Lagoon and at this location collected a small sample of oldsquaws for stomach analyses. Schamel (1974, 1978) described some aspects of the spring migration, the molt migration of seaducks, and the densities of shorebirds, gulls, terns, jaegers and seaducks in a portion of Gwydyr Bay near Egg Island, approximately 15 km east of Simpson Lagoon. Bergman et al. (1977) report the results of a 5-year study of waterbirds and wetland resources on the mainland coastal tundra near Storkersen Point, which is approximately 25 km east of the Simpson Lagoon study area. Similarly, Norton et al. (1975) and Hanson and Eberhardt (1976, 1977) report on the ecological relationships of the inland tundra avifauna near Prudhoe Bay, approximately 40 km east of Simpson Lagoon.

Migration in the Point Barrow area has been studied by Thompson and Person (1963), Johnson (1971) and Timson (1976), and Flock (1973) used DEW radars to obtain a broader perspective of migration in the North Slope area. Martin (Univ. of Alaska, pers. comm., 1980) conducted coastal bird migration watches during spring 1979 and has recorded the density of nesting birds on tundra plots during summer 1979 near Brownlow Point, Alaska.

Derksen et al. (1977) conducted habitat analyses during 1977 and reported on waterbird populations at tundra locations in National Petroleum Reserve-A, west of the Colville River, Alaska. King (1977) has reported on aerial surveys of birds on tundra habitats in National Petroleum Reserve-A. During July to September 1978 and 1979, Spindler (1978a, b, 1979) conducted aerial surveys of snow geese and other terrestrial birds on the coastal plain of northeastern Alaska and conducted aerial surveys of waterbirds associated with the coastal lagoons adjacent to the Arctic National Wildlife Range, northeastern Alaska.

Bartels (1973) conducted aerial surveys and presented estimates of densities of oldsquaws and other waterfowl along a series of nearshore marine transects in the Prudhoe Bay area of Alaska. Gollop and Richardson (1974) and LGL (unpublished 1973 data) summarized the results of aerial surveys of the bays, spits, lagoons and barrier islands located between Shingle Point, Yukon Territory, and Prudhoe Bay, Alaska, during June through August 1973. Harrison (1977) conducted aerial surveys offshore and along the coast of the Alaskan Beaufort Sea during July and August 1976; he presented densities of oldsquaws at several coastal locations between Barrow and the U.S.-Canada border.

STUDY AREA

The study area chosen for intensive ornithological investigations was the Jones Islands-Simpson Lagoon system. For comparative purposes, intermittent investigations were also conducted in adjacent areas during 1977. During 1978, systematic and more extensive ornithological investigations were conducted as far west as Atigaru Point and as far east as the U.S.-Canada border; a less intensive program of similar extent was conducted during 1979.

The Jones Islands have been defined as all islands, spits and reefs from Spy Island to Cottle Island (6.4 km^2, Fig. 1). During 1978, Thetis Island, a 1.6 km^2 gravel and sand island off the Colville Delta and west of Spy Island, was also included in the study area. The tundra-covered portions of Pingok, Peat, Bertoncini, Bodfish and Cottle Islands occupy an area of approximately 3.8 km^2 and are characterized by poor soils (Everett 1975) and tundra vegetation of low growth form (Spetzman 1959; Wiggins and Thomas 1962; Nieland and Hok 1975; Webber and Walker 1975). The remaining 2.6 km^2 of island habitat on the Jones Islands, located principally on Spy, Leavitt and Cottle islands, consists of unvegetated gravel, sand and silt.

Simpson Lagoon has been defined as that area east of a line from the west end of Spy Island to Oliktok Point, and west of a line from the east end of Cottle Island to Beechey Point (Fig. 1). This area occupies approximately 160 km^2, of which approximately 102 km^2 is at least 1.82 m (6 ft) deep. The deepest known point in the lagoon, located immediately off the east end of Spy Island, is 4 m deep. A trough, varying in width from 0.3 km at the east end of the lagoon to 5 km at the west end of the lagoon, and varying in depth from 2 to 3 m, runs the length of Simpson Lagoon. The remaining 58 km^2 of lagoon area is shallower than 1.82 m; almost two-thirds of these shallow waters lie along the south shore of Simpson Lagoon. (Planimetry conducted on U.S. Dept. Commerce, Coast and Geodetic Survey, Chart No. 9471, 4th edition, May, 1973.)

Also included within the study area is a 32 km x 20 m (0.64 km^2) strip of coastline that includes beaches, adjoining spits and adjacent sand bars along the mainland shoreline between Oliktok Point and Beechey

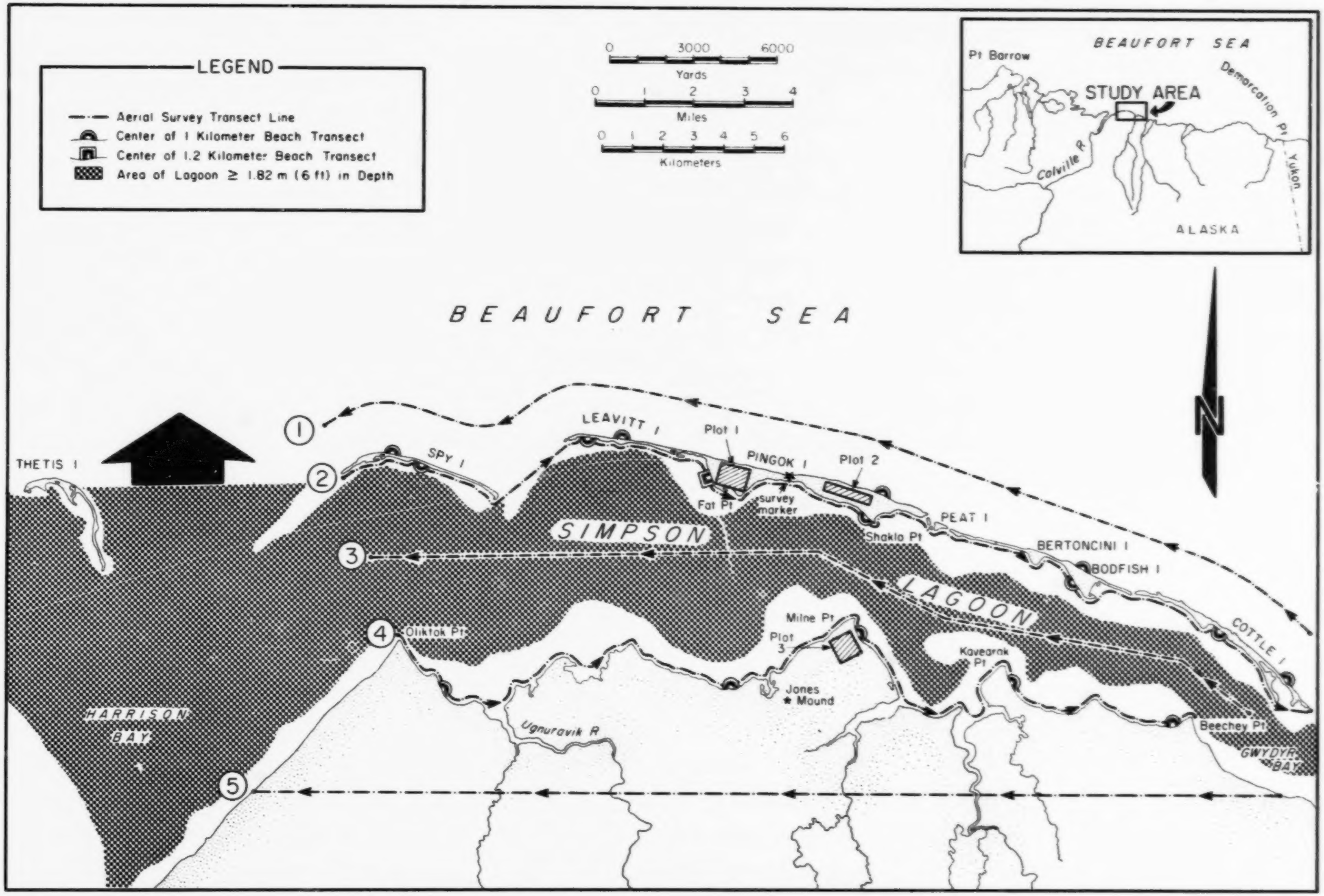
LEGEND
Aerial Survey Transect Line
Center of 1 Kilometer Beach Transect
Center of 1.2 Kilometer Beach Transect
Area of Lagoon ≥ 1.82 m (6 ft) in Depth
0 3000 6000
Yards
0 1 2 3 4
Miles
0 1 2 3 4 5 6
Kilometers
Pt Barrow
BEAUFORT SEA
STUDY AREA
Demarcation Pt
Colville R
Yukon
ALASKA
BEAUFORT SEA
N
①
②
③
④
⑤
THETIS I
SPY I
LEAVITT I
Plot 1
PINGOK I
Plot 2
Fat Pt
survey marker
SIMPSON
Shaklo Pt
PEAT I
BERTONCINI I
BODFISH I
LAGOON
COTTLE I
Milne Pt
Plot 3
Kavearak Pt
Oliktok Pt
Jones Mound
Beechey Pt
GWYDYR BAY
HARRISON BAY
Ugnuravik R

Figure 1. Jones Islands-Simpson Lagoon Study Area.

BEST DOCUMENT AVAILABLE

Point. This strip includes most of the driftwood and debris along this portion of the Beaufort Sea coast.

In order to compare avian use of the barrier island-lagoon study area with that of immediately adjacent marine and mainland areas, regular surveys were conducted seaward and landward of the intensive study area. The marine area was sampled along a 35 km x 0.4 km transect parallel to and about 2 km seaward from the contiguous Jones Islands (Cottle Island to Spy Island). The mainland area was sampled along a 35 km x 0.4 km transect located about 4 km inland from the shoreline between Oliktok Point and Beechey Point (Fig. 1).

During surveys conducted in 1978, 17 additional transects were established: 6 were in the shallow waters adjacent to the Colville River delta, west of Simpson Lagoon; 11 were along the barrier islands and lagoon systems east of Simpson Lagoon as far as the U.S.-Canada border (Fig. 2).

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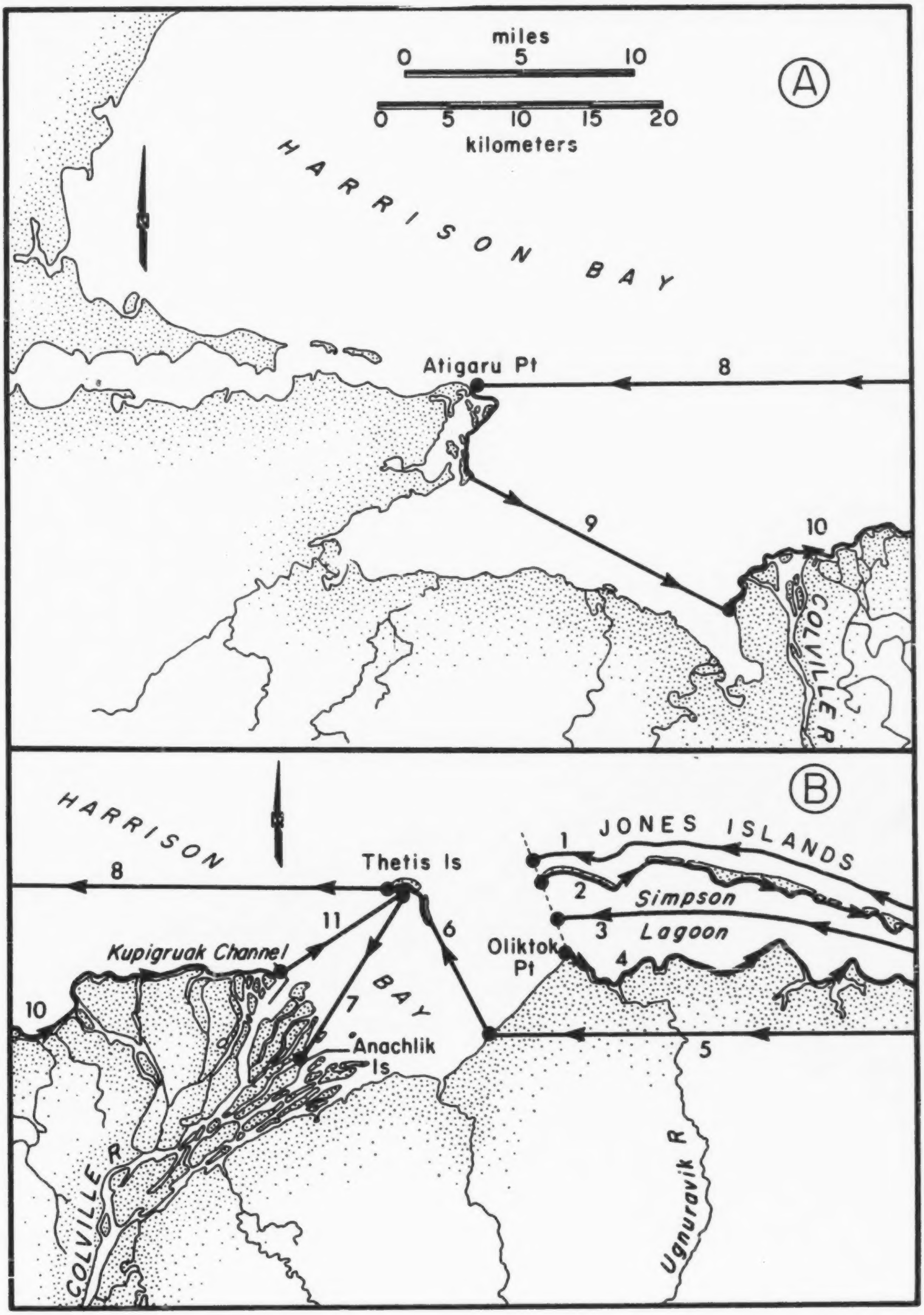
A
miles
0
5
10
0
5
10
15
20
kilometers
HARRISON BAY
Atigaru Pt
8
9
10
COLVILLE R
B
HARRISON
BAY
8
Thetis Is
11
6
7
Kupigruak Channel
10
Anachlik Is
JONES ISLANDS
1
2
Simpson
3
Lagoon
Oliktok Pt
4
5
Ugnuravik R
COLVILLE R

Figure 2. Locations of aerial survey transects in areas west (maps A and B) and east (maps C through G) of the Jones Islands-Simpson Lagoon study area.

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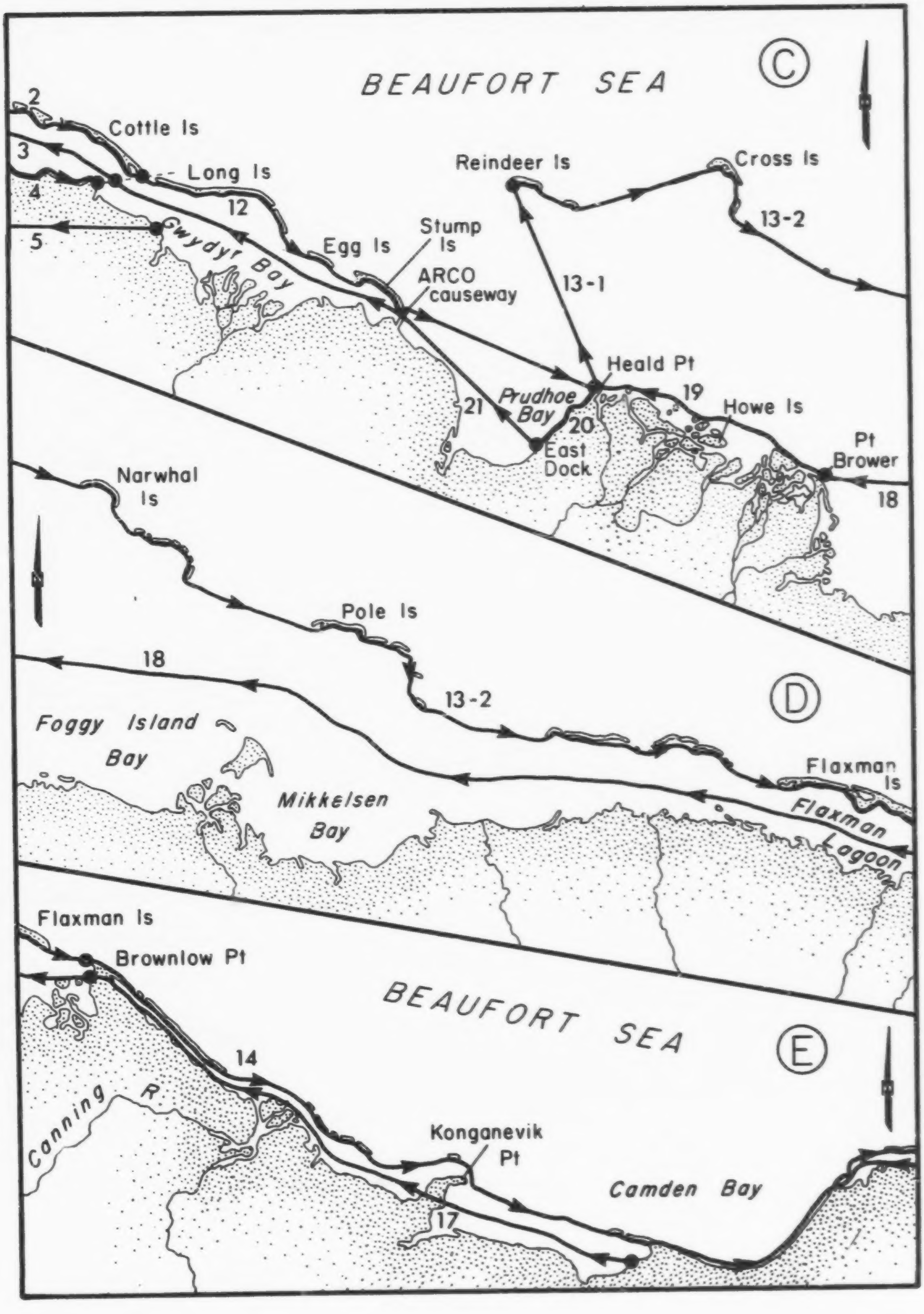
BEAUFORT SEA
C
2
Cottle Is
3
Long Is
4
12
5
Gwydyr Bay
Egg Is
Stump Is
ARCO causeway
Reindeer Is
Cross Is
13-2
13-1
Heald Pt
19
Howe Is
21
Prudhoe Bay
20
East Dock
Pt Brower
18
Narwhal Is
Pole Is
18
13-2
D
Foggy Island Bay
Mikkelsen Bay
Flaxman Is
Flaxman Lagoon
Flaxman Is
Brownlow Pt
BEAUFORT SEA
14
E
Canning R.
Konganevik Pt
Camden Bay
17

Figure 2 (cont'd)

BEST DOCUMENT AVAILABLE

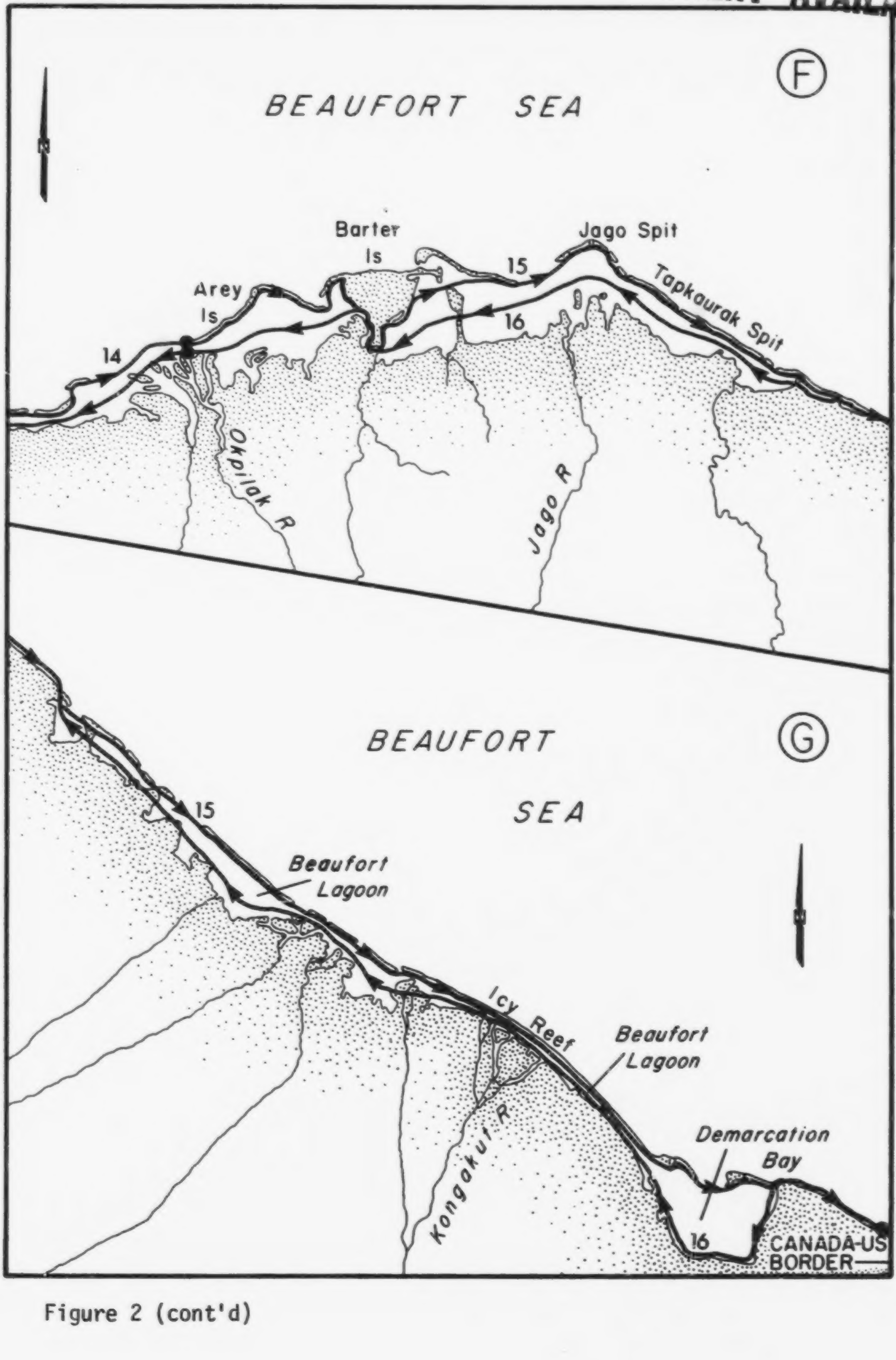
F
BEAUFORT SEA
Barter Is
Jago Spit
Arey Is
15
16
14
Tapkaurak Spit
Okpilak R
Jago R
G
BEAUFORT SEA
15
Beaufort Lagoon
Icy Reef
Beaufort Lagoon
Demarcation Bay
Kongakut R
16
CANADA-US BORDER

Figure 2 (cont'd)

METHODS AND RATIONALE OF DATA COLLECTION

Migration Studies

Three major migrations of marine-associated birds occur along the coast of the Beaufort Sea: spring migration, mid-summer molt migration, and fall migration. During these migrations, birds usually occur in flocks and may be both spatially and temporally concentrated in certain lagoon habitats.

Spring migration in the Beaufort Sea area occurs during a critical period because at this time there is little open water in normal years. In nearshore regions the only areas of open water consist of river and stream water that has flowed out over the landfast ice. Under certain circumstances, high mortality of marine-associated birds can occur from natural causes during spring (Barry 1968). A visual and radar study in the northern Yukon during 1975 has shown that spring migration there is highly concentrated along the Beaufort Sea coast (Johnson et al. 1975; Richardson et al. 1975). An oil spill at this time into a natural or man-made area of open water might kill large numbers of waterbirds. Hence, we studied spring migration intensively. We monitored migration by radar in 1977 and by visual methods in both 1977 and 1978. For comparative purposes, we have included some of our 1975 observations along the Yukon coast in this report.

The westward molt migration by male seaducks generally occurs during late June and July. Fewer species and individuals are involved in this migration than in the spring migration. The numbers of migrants that use (i.e., land in) nearshore waters around barrier islands and in lagoons are larger during molt migration than in spring, but nonetheless are still small. Most coastal lagoon habitats remain predominantly ice-covered until early to mid-July, and until that time the main areas of open water available to molt migrants in nearshore areas are narrow shoreleads and more extensive areas off the mouths of rivers.

The westward fall migration out of the Beaufort Sea generally involves more species than does the molt migration, and movements normally occur on a broader temporal and spatial scale within the coastal Beaufort Sea area than during either the spring or molt migration. All coastal habitats are available to most fall migrants.

Spring Migration

Radar Monitoring During Spring 1977. Radar data were obtained from the Oliktok Point, Alaska, DEW surveillance radar (70°30'N, 149°53'W). This radar is located at the southwest corner of Simpson Lagoon, and was known (Flock 1973) to be suitable for monitoring bird migration. Radar data were obtained on 18 May and from 26 May to 17 June 1977. The methods used were virtually identical to those used by Richardson et al. (1975) to study spring bird migration along part of the Canadian Beaufort Sea coast.

Time-lapse film of the Plan Position Indicator (PPI) display was obtained almost continuously on 18 May and from 26 May to 17 June 1977 at a rate of one 35 mm frame every antenna revolution. During time-lapse filming, the PPI displayed an area of radius 74 km (40 n. mi.).

Polaroid photographs of the PPI were obtained during the same dates, usually three times per day at about 08:00, 16:00 and 22:00 AST. Display radii of both 74 and 37 km were photographed, and for each of these radii separate photos of one antenna sweep and 6 sweeps were obtained. When 6-sweep photos were made, the shutter was closed during the fifth sweep. On these photos each bird echo appeared as a streak, and the polarity of movement was often evident from the absence of an echo for the fifth sweep. The main purposes of these photos were to provide 'real-time' radar data and to ensure against total loss of data from any malfunctions of the time-lapse camera.

Preliminary examination of our films indicated that well-defined eastward and westward spring migrations were detected consistently, and that these migrations were evident far inland and far offshore as well as near the coast. Very few bird echoes moved south (*cf.* Flock 1973) or north. Hence, characteristics of east and west movement were recorded separately from each of five parts of the radar display: (1, 2) 50 and 20 km inland, (3) over the coast and adjacent Simpson Lagoon, and (4, 5) 20 and 50 km north of Oliktok over the frozen Beaufort Sea. Data were recorded from the time-lapse films at 3-h intervals (00:00, 03:00, ..., 21:00 AST).

For each 3-h interval, the amounts (densities) of east and west migration in each area were assessed by eye. Migration density was recorded on the 0 to 8 ordinal scale (Richardson 1972) used in numerous previous radar studies. Reanalysis of data obtained from the Komakuk, Y.T., DEW radar by Richardson et al. (1975:124) provides calibration for levels 0-6 of the ordinal scale:

Level 0 corresponds to 0 bird echoes per 10 km of front (measured perpendicular to mean flight direction) per hour

1	5 ± 3 echoes/10 km·h (mean ± SD)
2	14 ± 3
3	22 ± 4
4	35 ± 10
5	83 ± 32
6	204 ± 13

Densities 7 and 8 were never encountered during either this or the Komakuk study. All film analysis in both studies was done by one individual (W.J. Richardson), thereby maximizing comparability of the results.

Modal flight directions (tracks) of birds moving generally east or west were estimated (separately) by eye to the nearest 10° for each 3-h interval. In addition, flight paths of individual echoes were occasionally traced from the time-lapse film for detailed analysis of flight directions and routes.

Visual Migration Watches During Spring 1977. Daily visual migration watches were conducted from 17 May to 15 June 1977 at Oliktok Point, and from 6 to 14 June at two sites on Pingok Island, both located 12 km NE of Oliktok. At each site, one observer conducted watches on a regular schedule. On most days, watches were conducted for three 2-h periods, usually 09:00-11:00, 13:00-15:00 and 19:00-21:00 AST. Field procedures are described by Johnson et al. (1975). Briefly, for each individual or group seen, we recorded the number, time, age and sex composition (if determinable), direction, height, distance from shore, behavior (flying, sitting, circling, landing, etc.), habitat, and 'migrant status'. The last of these variables was our assessment of whether the bird was actively migrating, possibly migrating, or engaged in a local activity (sitting, local flying, etc.). All data were dictated into tape recorders in the field and later transcribed onto coding forms for computer processing.

At Oliktok Point, the migration watch was conducted from the top of a fuel storage tank from a level about 7 m above sea level (ASL). This location afforded good visibility on all azimuths except 205°-225° where buildings and radar apparatus about 1.6 km away partially obstructed visibility. The lagoon surface was frozen and smooth, but after 8 June much of the lagoon ice was covered by runoff water from streams to the east. To facilitate estimation of distances of birds, stakes were positioned at 500 yard (457 m) intervals from 500 to 3000 yd north of the end of Oliktok Point. Binoculars (9x or 10x) and spotting telescopes (20-45 x Zoom) were used. On clear days flying birds could often be detected and classified at least to major taxonomic category (i.e., loon, waterfowl, gull, etc.) at distances as great as 6 km, which is the distance from Oliktok Point north to Spy Island.

The two migration watch stations on Pingok Island were located at the extreme western end of the tundra-covered portion of the island. One post was situated on the southwest shore and the other about 6 m ASL atop a building located some 40 m south from the north shore. The observer at the northern post recorded movements seaward of the barrier islands. Rough ice and pressure ridges obstructed visibility of low-flying birds beyond about 3 km seaward. The observer at the southern post recorded movements lagoonward of the island. The southern post was approximately 300 m south of the northern post, and although this post was not elevated, the lagoon surface was smooth and visibility was unobstructed to the mainland coast, approximately 7 km to the south.

Visual Migration Watches During Spring 1978. A twice-daily schedule of watches was established during the period 6 to 25 June 1978. The watches were conducted from a platform approximately 6 m ASL atop a building located approximately 1.5 km southeast of the tip of Milne Pt. and 50 m inland--midway along the south shore of Simpson Lagoon. Procedures were the same as those in spring 1977.

During both years, for purposes of analysis, active migrants were separated from local residents and 'status uncertain' birds on the basis of the 'migrant status' and behavior codes recorded in the field. In general, only birds that were in sustained flight and that maintained an eastward (30°-150°) or westward (210°-330°) course were treated as migrants.

Mid-Summer Molt Migration

Data concerning the mid-summer molt migration of male seaducks (oldsquaws, scoters, common and king eiders) were collected visually on many of the days from 26 June to 28 July during both 1977 and 1978. Radar was not used.

During 1977, it was not possible to maintain a rigid daily schedule of migration watches. The amount of time devoted to systematic migration watches depended on the weather (if fog was present throughout the study area, no watches were conducted), other duties of higher priority, and the apparent volume of bird migration. One observer used the elevated north post on Pingok Island (as described above). He recorded all birds seen regardless of whether they flew over the islands, lagoon or sea. Watches were most commonly conducted between 08:00 and 10:00 AST and between 20:00 and 22:00 AST. When weather permitted and especially when the volume of migration was high, longer and more frequent watches were conducted. Periods when watches were conducted are listed below:

Date	Number of Hours	Time (AST)
June 26	2.5	09:30-11:00; 19:30-20:30*
July 2	3.75	14:00-15:00*; 16:00-17:00*; 18:15-19:00; 20:00-21:00
3	6	08:00-09:00; 10:00-11:00; 12:00-13:00; 14:00-15:00; 17:00-18:00; 20:00-21:00*
4	5	08:00-09:00; 10:00-11:00; 12:00-13:00; 14:00-15:00; 17:00-18:00*
7	1	08:45-09:45
12	2	20:15-22:15
13	2	08:15-10:15
14	2	08:15-10:15
15	4	08:00-10:00; 20:00-22:00
20	2	20:00-22:00
21	2	08:20-10:20
22	2	20:45-22:45
23	3	08:35-10:35; 20:30-21:30
24	2.5	09:00-10:00; 20:30-22:00
25	1	08:50-10:50

*Visibility <3 km during this watch.

During 1978, the systematic schedule of visual watches established during spring was maintained until 28 July except during the peak of the molt migration. During this peak period (3 to 7 July), watches were conducted during fog free periods on alternate hours from 07:00 to 23:00 AST.

During the mid-summer period in both 1977 and 1978, all flocks or aggregations of birds seen during other research activities were recorded and included in some analyses of molt migration. Observations during systematic watches were recorded on tape recorders; additional observations were recorded in notebooks and also coded for keypunching. Definite or probable migrants were separated from local residents on the basis of the same behavioral criteria as in spring.

Certain observations of molt migration along the Yukon coast have been summarized, for comparative purposes, in this report. These data were obtained during previous studies by Gollop and Davis (1974) in 1972 and by Johnson et al. (1975) in 1975.

Fall Migration

During 1977, data concerning 'fall' migration were collected from 21 August to 22 September. Radar was not used. Watches were conducted by one observer from the elevated north post on Pingok Island using the same procedures as used during molt migration. Migration watches were usually conducted within the periods 07:00 to 11:00 and/or 15:00 to 17:00 AST.

During 1978, incidental observations concerning 'fall' migration were collected intermittently from 1 August to 15 October. Radar was not used and systematic migration watches were not conducted. All flocks of birds and other apparent migrants observed during the course of other research activities were recorded in notebooks, coded for keypunching, and included in the analysis of fall migration.

Nesting Studies

Both Gavin (1976) and Divoky (1978b) have presented estimates, based on primarily non-quantitative methods, of the numbers of waterbirds nesting on the Jones Islands. An accurate assessment of numbers of birds nesting on barrier island habitats can only be made by establishing and thoroughly searching plots or by systematically searching all available nesting habitats. Because of the large amount of tundra habitat available on Pingok Island (see "Study Area"), two large plots were established during 1977 on tundra portions of this island. The total area of all the other barrier islands was completely surveyed during 1977. One of these plots on Pingok Island was re-established during 1978 and a comparative plot on the mainland tundra was established. In general, nesting surveys on barrier islands during 1978 were less extensive than during 1977, and were designed to monitor specific barrier island habitats at specific locations.

Survey Methods

On 16-20 June 1977 two tundra plots, one covering 0.63 km^2 (Plot 1) and another covering 0.30 km^2 (Plot 2), were established on Pingok Island (Fig. 1). A compass and 100 m steel tape were used to measure and stake 100 m intervals within the plots. Between 20 June and 20 July 1977, these two island tundra plots were surveyed for nesting birds twice, and all tundra habitats on Peat, Bertoncini, Bodfish and Cottle Islands (total area 0.87 km^2) were surveyed for nesting birds once. During surveys, two or three observers flushed birds from their nests by dragging a 50 m length of rope perpendicular to the direction of their movement across the tundra. Most birds flushed in advance of the oncoming rope, although some did not flush until the rope passed over them.

On 24 to 27 June 1978, Plot 2 (0.30 km^2) on Pingok Island was re-established and an additional comparative plot covering 0.25 km^2 (Plot 3) was established on the mainland tundra near Milne Pt. (Fig. 1). Between 24 June and 12 July 1978, both of these plots were surveyed twice by three observers using a rope drag as described above. Plot 1 on Pingok Island and the tundra portions of the other barrier islands were not surveyed during 1978.

From 21 to 24 June 1977, the locations and numbers of all territorial males (N♂♂) of all species of birds seen on Plots 1 and 2 on Pingok Island were recorded. Similar data concerning territorial males on Plots 2 and 3 during 1978 were not recorded.

During 1 to 7 July 1977, the 2.6 km^2 of barrier island habitat covered by gravel, sand and silt was surveyed by searching all the driftwood rows and piles of debris where, in the Beaufort Sea area, species such as common eiders, glaucous gulls and arctic terns may nest (Schamel 1974; Divoky 1978b). During 1978, such surveys of gravel and sand islands were conducted during 1 to 3 July and were restricted to Spy Island (1.5 km^2) and adjacent Thetis Island (1.6 km^2). Thetis Island was not surveyed in 1977. Birds nesting on Spy Island traditionally have suffered predation by Arctic foxes (J.W. Helmericks, pers. comm. 1977; Divoky 1978b; Johnson 1978). In contrast, Arctic foxes have seldom been recorded on Thetis Island.

When an active nest (a nest with at least one egg or young) was discovered, its position was mapped and a stake was placed at a given distance and direction from the nest. The stake was labelled, colored flagging tape was attached, and the following information was recorded:

1. The presence or absence and behavior of any adult birds near the nest.
2. The number of eggs and/or young present in or near the nest.
3. A description of the substrate, nest material and cover near the nest.
4. Any evidence of predation or recent activity or predators near the nest site.

Nests constructed during previous years, destroyed nests and partially completed nests (including nest scrapes) were also recorded, and their positions mapped.

Molting and Pre-Migratory Staging Studies

Most waterfowl undergo a summer molt during which they gradually replace their contour feathers and simultaneously lose all of their flight feathers. Seaducks (primarily post-breeding males and some females) migrate along specific traditional routes to specific locations where they concentrate into flocks and undergo this molt (Salomonsen 1968). Hall (1975) and Gavin (1976) have previously suggested that Simpson Lagoon may be an important summer molting area for oldsquaws, and Bartonek (1969), Bartels (1973), Schweinsburg (1974a) and Divoky (1978b) have suggested that the barrier island-lagoon systems along the Alaskan Beaufort Sea coast are important summer molting and post-breeding concentration areas for seaducks--primarily oldsquaws.

After they leave their tundra rearing areas and before they migrate out of the Beaufort Sea area, immatures of certain species of shorebirds also concentrate into large feeding flocks along the coastline. Connors and Risebrough (1976, 1977) and Connors et al. (1978) have indicated that coastal locations in the western portion of the Beaufort Sea are important concentration areas for immature phalaropes. This process of pre-migratory concentration is called "staging". Any species (in this study, primarily oldsquaws, phalaropes, glaucous gulls and arctic terns) that was not molting and that was concentrated for a significant period of time in the Jones Islands-Simpson Lagoon study area and in the adjacent barrier island-lagoon systems was considered to be staging.

Specific survey programs and methods were designed to quantify efficiently and accurately the abundance and distribution of molting and staging birds in the study area.

Aerial surveys provide a method for rapidly and systematically recording numbers and distributions of medium-sized and large birds, such as oldsquaws, gulls, terns and loons, in a wide area. The aerial method is applicable over land, water and ice.

Shoreline surveys from small boats were used to record numbers and distributions of small shoreline-associated birds such as phalaropes, sandpipers and plovers. Gulls and terns, which also may associate with shorelines, especially when feeding, were also recorded during boat surveys. Hence, large species of shoreline-associated birds such as gulls and terns were surveyed equally well from both aircraft and boats. Those large birds associated with open water areas away from shorelines were surveyed best from aircraft.

Aerial Surveys During 1977 and 1978

Aerial surveys were conducted on seven occasions during 1977 (5 June to 22 September; Appendix I), on ten occasions during 1978 (23 June to 23 September; Appendix II) and on four occasions during 1979 (22 June to 23 September; Appendix III). Each survey consisted of one flight along each of five to 22 permanent transect strips, each located in a specific type of habitat (Table 1). During 1977, only transects located in the Jones Islands-Simpson Lagoon area (transects 1-5) were surveyed. In order

Table 1. Aerial survey transect descriptions, Beaufort Sea, Alaska, 1977-1979*.

Transect Number	Transect Length (km)	Habitat Type	Location
1	35.4	Offshore Marine	1.6 km seaward of the Jones Islands, E to W.
2	37.0	Lagoon - south shoreline of Barrier Islands	From W end Spy Is., E to E end Cottle Is.
3	30.6	Mid-lagoon	From Beechey Pt., W to Oliktok Pt.
4	32.2	Lagoon - Mainland Shoreline	From Oliktok Pt., E to Beechey Pt.
5	33.8	Mainland tundra	4 km inland from Simpson Lagoon, E to W.
6	13.8	Mid-lagoon	Harrison Bay from 6 km S of Oliktok Pt., NW to Thetis Is.
7	16.1	Mid-lagoon	Harrison Bay, from Thetis Is., SW to Anachlik Is.
8	56.3	Unprotected Bay	Harrison Bay, from Thetis Is., W to Atigaru Pt.
9	30.3	Unprotected Bay	Harrison Bay, from Atigaru Pt., SE to E side of Colville R. delta.
10	35.1	River Delta	From E side of Colville R. delta to W side of mouth of Kupigruak channel.
11	12.1	Mid-lagoon	From W side of mouth of Kupigruak channel, NE to Thetis Is.
12	34.8	Lagoon - south shoreline of Barrier Islands and Protected Bay	From E end Cottle Is. to E end Stump Is., E across Prudhoe Bay to Heald Pt.
13.1	16.4	Semi-protected Sound	From Heald Pt., NW across Stefansson Sound to Reindeer Is.
13.2	123.9	Lagoon - south shoreline of Barrier Islands	From W end Reindeer Is., ESE to Brownlow Pt.
14	87.7	Lagoon - south shoreline of Barrier Islands	From Brownlow Pt., ENE to W end Arey Is.
15	152.1	Lagoon - south shoreline of Barrier Islands	From W end Arey Is., ESE to E end Demarcation Bay or to US-Canada Border.
16	144.7	Mid-lagoon	From US-Canada Border or E end Demarcation Bay, WNW to W end Arey Is.
17	86.1	Mid-lagoon	From W end Arey Is., WNW to Brownlow Pt.
18	81.3	Mid-lagoon	From Brownlow Pt., W to Pt. Brower.
19	17.4	River Delta	From Pt. Brower, W to Heald Pt.
20	6.4	Mainland Shoreline	From Heald Pt., S to East Dock Prudhoe Bay.
21	37.0	Mid-lagoon	From East Dock Prudhoe Bay, W to Beechey Pt.

*Transects 1-5 lie within the Jones Islands-Simpson Lagoon intensive study area and these transects were surveyed during 1977, 1978 and 1979. The remaining transects lie to the east and west of the intensive study area and were surveyed only during 1978 and 1979 (see Fig. 2A-G).

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to assess the validity of classifying the Jones Islands-Simpson Lagoon study area as a representative of the extensive barrier island-lagoon systems along the Alaskan Beaufort Sea coast, 16 additional transects were established during 1978 at locations both east and west of Simpson Lagoon and they were systematically surveyed. In 1978 and 1979, each single aerial survey consisted of flights along 12 to 22 and 12 to 20, respectively, different transects.

During the survey of the barrier island transects (Transect 2) in 1977, the aircraft was positioned directly over the center of the islands where they were narrower than the 400 m-wide transect strip. Along those portions of the islands that were wider than 400 m, the aircraft was maneuvered to a position 100 m lagoonward (south) of the south shoreline of the island. When surveying the mainland coast the aircraft was positioned 100 m lagoonward (north) of the mainland shoreline (see Appendix IV).

During the surveys of barrier islands and mainland coasts in 1978 and 1979, the aircraft was positioned 200 m lagoonward of the shorelines. The descriptions of all aerial survey transects are given in Table 1.

Aircraft flight procedures were standardized to the greatest extent possible. However, because it was necessary to use three different types of aircraft during 1977 and two different types during 1978, including both fixed- and rotary-wing aircraft, variations in flight speed, observer visibility and aircraft seating positions were unavoidable. All surveys in 1979 were conducted from a Cessna 206 fixed-wing aircraft.

Except for the 28-29 July 1977 survey, each survey during 1977 was conducted using a single aircraft on a single day (Appendix I). The 28-29 July 1977 survey was conducted over a two-day period and two different types of aircraft were used. A float-equipped aircraft was unavailable on 15 August 1977, so transects over open water were not surveyed on that date. During 1978, a fixed-wing aircraft was used for all aerial surveys except the survey on 15 July when a helicopter was used. During 1978, only the extensive surveys conducted on 5-6 August and 5-6 September required more than one day for completion (Appendix II). During 1979, two surveys were completed in a single day and two were completed over a 2-day period (see Appendix III). During all surveys, both observers recorded into portable tape recorders all birds seen on-transect

(≤200 m from aircraft) and off-transect (>200 m from aircraft). The information recorded was of four types: (1) systematic information about the transect, (2) systematic information about each bird sighting, (3) systematic information about the habitats below the aircraft at 2-min intervals, and (4) general remarks. All information except general remarks was numerically coded when transcribed later onto data forms. All transects were divided into 2-min intervals using a timing device. The timer was reset to zero at the start of each transect and it produced a sound audible to both observers at 2-min intervals. The general habitat type found within each 2-min interval was recorded by both observers, and the interval-number in which each bird was seen was recorded.

When counts by both observers were combined, it was possible to calculate an estimate of the density of birds per square kilometer.

Shoreline Transects

Shoreline transects were designed primarily to measure the distribution and abundance of shorebirds, gulls and terns along the three types of beaches common in the study area. During the third week of July 1977 15 shoreline transects were established. Five transects were located along seaward shorelines of the barrier islands, five along lagoonward shorelines of the islands, and five along mainland shorelines (see Fig. 1). Each transect was 1.0 km long and 20 m wide (0.02 km^2). The start and end points of each transect were permanently marked by driving 2.5 m pipes approximately 0.5 m into the beach substrate approximately 10 m from the shoreline.

During 1977, each of these shoreline transects was surveyed on 1, 16 and 24 August, and on 1 and 14 September. During 1978, these 15 shoreline transects were surveyed at 5-day intervals from 31 July to 3 September. Another shoreline transect, established along a lagoonward beach on the west end of Pingok Island (Fig. 1), was 1.2 km long by approximately 20 m wide and was surveyed more frequently--18 times from 2 August to 18 September 1977 and 16 times from 2 August to 3 September 1978.

During each survey, all 15 permanent transects were surveyed within one 8-h period with the aid of binoculars from a boat moving parallel to the transect. The boat was positioned approximately 50 m from the outer edge of the transect, and did not appear to disturb shorebirds along the shoreline. During the 1977 surveys, one observer operated the boat while a second systematically recorded data into a portable tape recorder. During 1978, a single observer conducted most of the shoreline surveys. The following information was recorded about each transect and any birds sighted:

1. The date, transect number, observers, start and end time of the survey, weather and water conditions, and direction of travel.
2. The number of individuals of each bird species present on-transect (within 10 m of the shoreline) or off-transect (greater than 10 m from the shoreline).
3. The estimated distance of each bird or group of birds from the shoreline, and whether the birds were sighted on the beach or in the water.
4. The behavior of each bird or group of birds sighted on-transect or off-transect.

Feeding Studies

Studies of the feeding ecology of marine birds provide a key link in the interpretation of relationships among physical parameters, biological productivity, and distribution and abundance of marine birds in barrier island-lagoon systems. Specific questions regarding the age, sex, stage of molt, physical condition and identity of food organisms consumed by birds during the various stages of bird abundance and lagoon productivity can be answered only by collecting birds.

The primary purpose of the avian feeding ecology studies was to determine which food organisms comprised the important proportions of the diets of those species of birds most widely distributed and most abundant in the study area. During 1977 the key avian species were (1) oldsquaws, (2) red and northern phalaropes (generally treated as a single group), and (3) glaucous gulls. During 1978, only oldsquaws and the phalaropes were treated as key species. We chose a qualitative method (see Hynes 1950 and Griffiths et al. 1975) for assessing the relative importance of food taxa found in bird stomachs and in bird feeding habitats during 1977 and 1978 because this method combined the following advantages:

1. It is efficient and relatively accurate in estimating the relative importance of particular food taxa.
2. It is easily used under field conditions and requires no special apparatus for measurement of organisms.
3. It does not give the potentially misleading impression of accuracy given by some other methods that measure stomach contents more precisely but make no better allowance for sampling problems and differential digestion rates.

During both 1977 and 1978, comparisons were made of the diet of oldsquaws as determined by the qualitative Hynes point method and by more quantitative methods of measurement.

Collections of Birds and Habitat Samples

From 17 June to 19 September 1977, 210 specimens of four avian species (oldsquaw, red and northern phalaropes, and glaucous gull) were obtained in the Simpson Lagoon-Jones Islands area. During the last two weeks of June 1977, seven oldsquaws were accidentally caught in gill nets set as part of the aquatic biology investigations; the stomach contents of these birds were retained. The remaining 203 specimens were collected with a shotgun during the 11 July to 19 September 1977 period.

Samples of potential food organisms, hereafter referred to as habitat samples, were collected from the precise habitats in which birds were feeding when they were shot. These habitat samples were collected immediately after we collected the birds.

Between 28 June and 23 September 1978, 168 additional specimens of three avian species (oldsquaws and red and northern phalaropes) were collected in the Simpson Lagoon-Jones Islands area (glaucous gulls were not collected during 1978). On 28 June 1978, one oldsquaw was accidentally caught in a gill net; the stomach contents of this bird were retained. The remaining 167 specimens were collected with shotguns during the 10 July to 23 September 1978 period.

During 1979, 12 oldsquaws were collected opportunistically in association with the aerial survey program. On 1 September an immature male was collected from a brood of five accompanied by a flightless female on a lake 16 km inland from Simpson Lagoon. On that same date five flightless adult females were collected on another large tundra lake approximately

24 km inland from Simpson Lagoon. On 2 September five adult male oldsquaws were collected in the embayment along the south shoreline of Thetis Island; on 23 September an adult female was collected at this same location.

Oldsquaw. During 1977, 31 collections (excluding those caught in gill nets) of oldsquaws (mean=2.6 birds/collection) were made in Simpson Lagoon during the period 11 July to 14 September; the average depth where 77 of the 90 oldsquaws were collected was 2.09 m ± 1.55 m.* During 1978, 45 collections of oldsquaws (mean=2.4 birds/collection) were made in Simpson Lagoon during the period 10 July to 27 September; the average depth where 108 of the 109 oldsquaws were collected was 2.05 ± 1.60 m.

The general procedures followed for collecting oldsquaws and oldsquaw feeding habitat samples during 1977 were the following:

1. A flock of oldsquaws was located and watched briefly to determine whether some birds appeared to be feeding (diving). An estimate was made of the size of the flock.
2. Observers then sped into the flock, dropped an anchored buoy as the boat slowed, and collected as many birds as possible.
3. Birds were retrieved and labelled. To mitigate post-mortem digestion of any food items, the gut (proventriculus and ventriculus) and esophagus of each dead bird were injected with absolute isopropyl alchohol. The esophagus of each bird was then plugged with a paper wad.
4. Habitat sampling was initiated after the collecting party returned to the buoy.
    a. For each set of birds collected, two quantitative samples were obtained, one from the surface-water and another from the mid-water portions of the lagoon. This was accomplished by towing both a surface-supported neuston net and a submerged (1 m deep) macroplankton net (see Griffiths and Craig [1978] and Griffiths and Dillinger [1980] for more details).
    b. For each set of birds collected, one qualitative sample from the lagoon epibenthos was collected. From a stationary boat in the area of the buoy, a macroplankton net was manually towed across the bottom of the lagoon for a distance of approximately 10 m and at a speed of approximately 0.5-1.0 m/s.

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*All such values in this report are means ± standard deviations.

c. Habitat samples were immediately washed from the sampling nets into double-labelled 227-ml (8 oz) bottles and preserved in 10% neutral formalin.

During 1978, the same general procedures as during 1977 were followed for collecting oldsquaws except that, prior to making collections, some flocks of birds were watched more carefully and over a longer period of time than during 1977 to determine whether they appeared to be feeding (diving).

Also during 1978, habitat sampling procedures were different from those followed in 1977. No samples were taken from either the surface water or midwater layers of the lagoon at locations where oldsquaws were collected, but a quantitative method of sampling invertebrates from the epibenthos using a drop net was adopted (see Griffiths and Dillinger [1980] for more details).

Phalaropes and Glaucous Gull. Visual observations made during shoreline and aerial surveys indicated that during 1977 and 1978 phalaropes and glaucous gulls fed almost exclusively in shallow areas (<1 m deep) along shorelines and in bays. Therefore phalaropes (during 1977 and 1978) and glaucous gulls (during 1977), and associated feeding habitat samples, were collected in these shallow areas.

Phalaropes are very tame birds and large flocks were easily approached on foot as they fed along shorelines. They were collected while they fed and the post-mortem handling procedures were the same as those described for oldsquaws.

The glaucous gulls were initially considered to be a key species; therefore glaucous gulls and their feeding habitats were systematically sampled during 1977--28 glaucous gulls were collected during 1977. However, the 1977 studies indicated that glaucous gulls, by criteria established during the course of the Barrier Island-Lagoon Program, were not key species and that further collections and associated habitat sampling during 1978 were not justified. Glaucous gulls fed either singly or in loose aggregations during 1977; they were not easily approached on foot. We watched from a boat offshore to ascertain whether they appeared to be feeding--if they were, we approached as quickly as possible from a speeding boat. The exact location where the bird was feeding was visually noted as we approached. If a bird was collected, the same procedures described for the post-mortem handling of oldsquaws were applied.

During 1977, a single quantitative habitat sample was collected with a surface-supported neuston net at each shallow location where phalaropes or glaucous gulls were collected. The net was attached by a line to a 3-m pole and was towed manually from shore for approximately 50 m at an approximate speed of 1 to 1.5 m/s through waters about 1.5 m from shore and that varied in depth from 10 cm to 1 m. During 1978, identical equipment was used to sample phalarope feeding habitats; however, slightly different procedures were followed. Rather than take one sample along a 50 m stretch of shoreline, we took three samples, each of length 10 m, along three stretches of shoreline where the birds were feeding. Habitat samples were treated as described for oldsquaws.

Laboratory Techniques

Within 24 hours of collection all birds were dissected and food items found in the esophagi and guts (proventriculi and ventriculi) were preserved. The following procedures for measurement and dissection of birds were followed:

1. The flattened length of the right wing of each bird was measured (accurate within ± 0.5 mm) and the weight of each bird (accurate within 1 g) was determined using a Pesola spring balance.
2. The condition of the plumage and the stage of molt were recorded.
3. The amounts of subcutaneous and abdominal mesenteric fat were subjectively classified according to the OCS fat code: 1=none; 2=light; 3=moderate; 4=heavy; 5=excessively heavy. The thickness of subcutaneous fat present at a standard location on the right side of the breast of each bird was measured to the nearest 0.5 mm.
4. The sex organs of each bird were removed, measured and stored in Bouin's fixative solution. In females, the diameter of the largest ovum was measured to the nearest 0.5 mm. In males, the length and width of each testis were measured to the nearest 0.5 mm.
5. The esophagus and gut were removed as a single unit from each bird. During 1978, this unit was slit lengthwise, an arbitrary measure of fullness (Hynes 1950 and Griffiths et al. 1975; see below) was assigned to the total unit in

> the field, and a cursory and tentative description of the contents was recorded. These contents were then washed with 10% neutral formalin into a 227-ml double-labelled bottle. During 1977, no measure of fullness was assigned in the field, but all other procedures were the same. Because of the small size of food items consumed by phalaropes and because some food items were difficult to wash from their esophagi and guts, these organs were preserved also.

To assess and compare the importances of various food taxa in the diet of each of the key bird species during both 1977 and 1978, laboratory analysis of the stomach contents of each bird was necessary. During both years the preserved stomach contents and feeding habitat samples were sorted and an estimate was made of the relative volume of each major taxon (e.g., amphipod, mysid, copepod, isopod, etc.) by assigning points (Hynes 1950; Griffiths et al. 1975). Our laboratory method for assigning points differed in one major respect from the modified Hynes point method used in the field during 1978 and described by Griffiths et al. (1975). In the laboratory we assessed the total volume of the stomach contents after instead of before they had been removed from the stomach and bottled.

Twenty points were assigned to the fullest stomach analyzed of a particular species of bird. The fullness of each additional stomach from that species was subsequently gauged against the fullest stomach and a corresponding number of points was assigned. After the sample had been sorted, and after each major taxon had been bottled, the total number of points thus assigned to each stomach was partitioned among the major invertebrate taxa present according to the relative volume of each. No distinction was made between whole organisms and fractions thereof. Pieces of unidentified organisms were classified as such.

As noted above, feeding habitat samples for oldsquaws during 1977 were collected using three different types of sampling techniques, each designed to sample a different stratum of lagoon water. Two of these techniques used during 1977 were quantitative and the third (the epibenthic tow) was qualitative. In 1978 only epibenthic sampling was conducted and a quantitative method was adopted. Habitat samples for gulls and phalaropes during 1977 and for phalaropes during 1978 were collected by yet another method. Therefore, volumes of materials sampled using the various methods were not directly comparable either between years or between species, and only relative volumes of different taxa were considered.

Each habitat sample was sorted and bottled by major taxon. Twenty points were assigned to the total volume of each sample and then appropriate proportions of the total 20 points were assigned to the various major taxa in the sample. During 1977, the two most important taxa (mysids and amphipods) present in the stomachs and habitat samples of key bird species were further sorted, identified to the species level and weighed (formalin wet weight). For a size comparison, mysids and amphipods (20 individuals each) were randomly selected from each oldsquaw stomach, and from each oldsquaw habitat sample taken during 1977; these individuals were measured to the nearest millimeter. During 1978, a much more detailed system of sorting and measuring was adopted; all taxa present in the stomachs and habitat samples of key bird species were sorted to major taxa, identified to the species level, counted and weighed. (Length of the telson plus first urosome was also measured.) Further details of the sorting, counting, weighing and measuring procedures followed during 1977 and 1978 are described in Griffiths and Dillinger (1980).

MIGRATION STUDIES

Results

Spring Migration

Seasonal Timing. Previous observations in the Beaufort Sea area have shown that a few species of waterbirds (most notably common and king eiders plus glaucous gulls) migrate eastward through the area throughout much of May and into June (Johnson et al. 1975; Searing et al. 1975). However, peak spring migration of most species is from late May to mid June.

The Oliktok radar showed a few westbound but no eastbound migrants on 18 May 1977. No radar data were available on 19-25 May. Migration in both directions became increasingly prominent in the last week of May, and from 1 to 17 June the radar showed much migration in both directions (Fig. 3, 4). At least a few eastbound migrants were evident on the radar during every half-day interval from 26 May to 17 June, and at least a few westbound migrants on almost all occasions. Both eastbound and westbound migrants were evident far inland and offshore, as well as near the coast, throughout the late May to mid-June period (Fig. 3, 4). Despite the fact that less migration was visible to ground observers in mid-June than during 1-10 June (see below), radar showed only a slight reduction in eastward migration and no obvious reduction in westward migration. Most of these results are very similar to those obtained 375 km to the ESE along the Yukon coast in spring 1975 (Richardson et al. 1975). There both eastward and westward movements were conspicuous on radar until the study ended in early July.

For each species seen during the spring migrations of 1977 and 1978, dates of first observation (1977) and peak abundance (both years) are listed in Table 2. The results from 1977 are more comprehensive because observations began earlier (17 May 1977, 6 June 1978) and because observations were made from Pingok Island as well as the mainland shore during 6-14 June 1978. Hourly rates of eastward and westward migration of the common waterbird species are shown for each 5-day period in Figures 5-7.

Eastbound glaucous gulls were the only migrant waterbirds that were common in the Simpson Lagoon area in mid-May 1977, although a few white-fronted geese had arrived by then. No eiders were seen until 30 May

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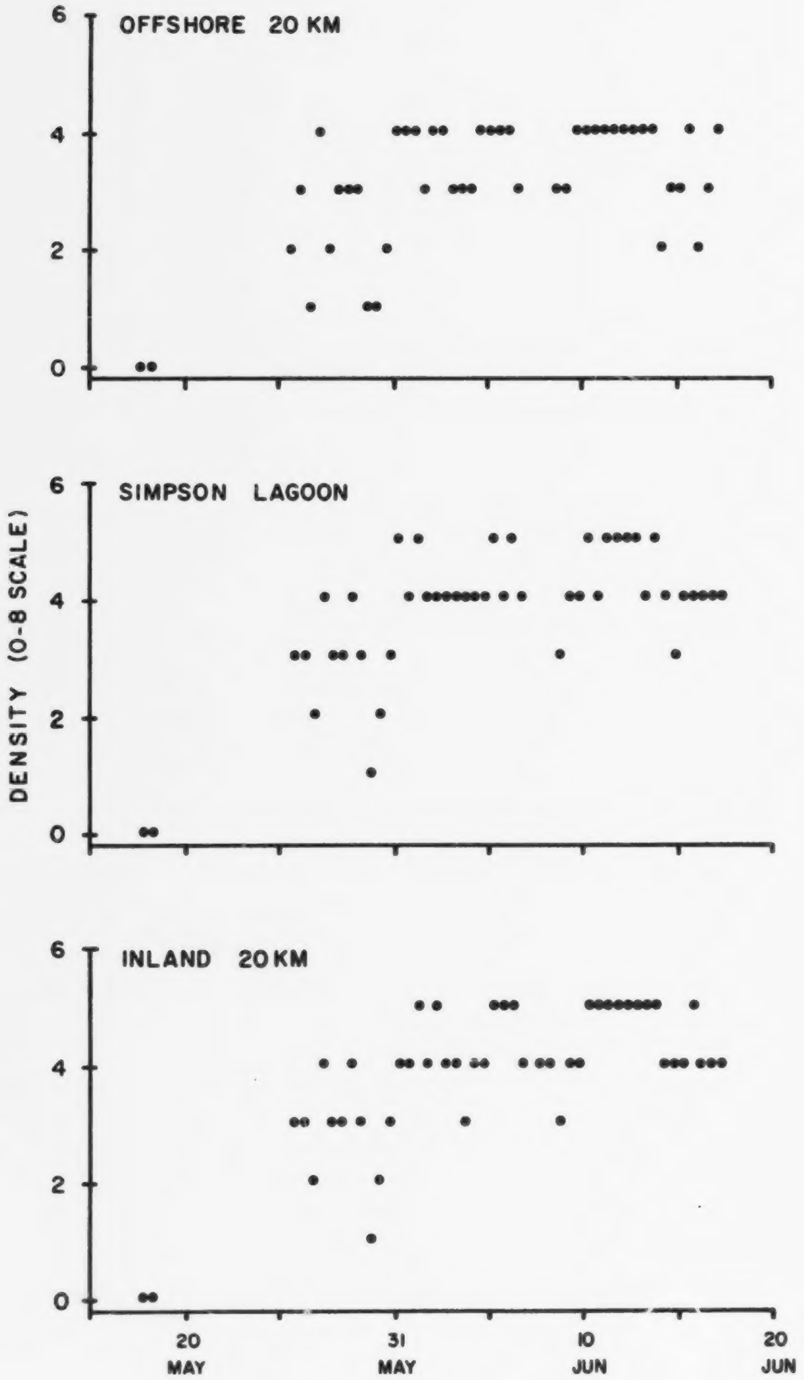

Figure 3. Density of eastward migration detected by Oliktok radar in relation to date, May-June 1977. Densities at 09:00 and 21:00 AST each day are shown.

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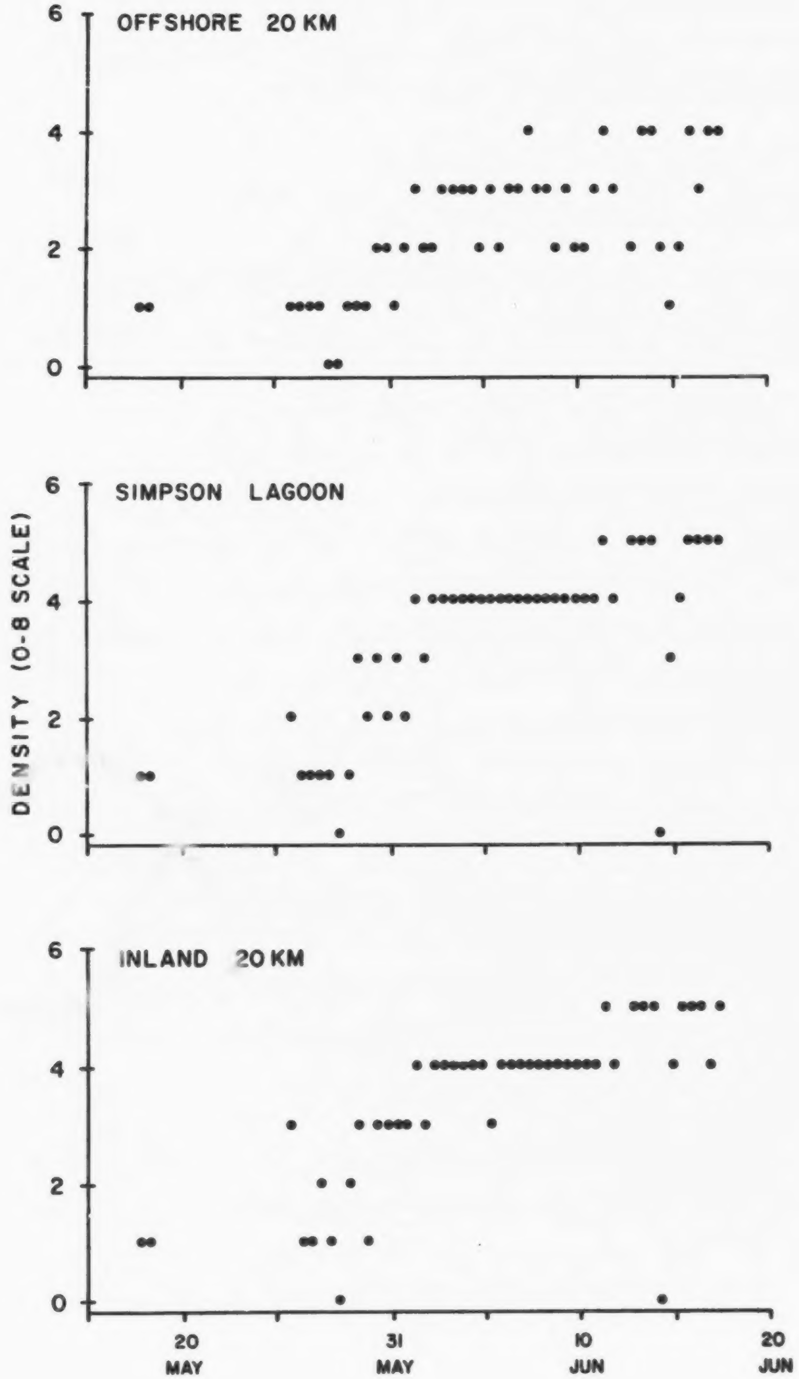

Figure 4. Density of westward migration detected by Oliktok radar in relation to date, May-June 1977. Densities at 09:00 and 21:00 AST each day are shown.

Table 2. Birds recorded during migration watches in spring 1977 at Oliktok Point and Pingok Island and in spring 1978 at Milne Point, Alaska. (Revised; supersedes Table 5 of Johnson 1979).

Species	First Observed[a]	Approximate Number Seen[b]		Periods of Peak Abundance		Predominant Migration Direction[c]		Peak Migration Rate (# Birds/h)[d]	
	(1977)	(1977)	(1978)	(1977)	(1978)	(1977)	(1978)	(1977)	(1978)
Yellow-billed Loon	3 Ju	26 (32)	- (2)	3-9 Ju	-	E	-	0.8	-
Arctic Loon	9 Ju	39 (52)	21 (80)	9-13 Ju	16-18 Ju	E	E	1.5	2.3
Red-throated Loon	9 Ju	25 (28)	2 (9)	9-13 Ju	21 Ju	E	E	0.9	0.4
Unidentified Loons	2 Ju	289 (313)	32 (67)	3-13 Ju	16-19 Ju	E	E	4.5	4.0
Whistling Swan	31 Ma	- (16)	- (6)	-	-	-	-	-	-
Brant	31 Ma	592 (1018)	329 (2707)	9-14 Ju	11 Ju	E	E	14.8	164.5
Lesser Snow Goose	10 Ju	19 (4)	- (14)[f]	10-11 Ju	-	E	-	0.7	-
White-fronted Goose	17 Ma	- (208)	7 (45)	-	18-19 Ju	L	W	-	1.0
Canada Goose	5 Ju	- (-)	85 (85)	-	18 Ju	-	W	-	21.3
Unidentified Dark Goose	3 Ju	256 (284)	38 (126)	5-10 Ju	20 Ju	E	W	14.3	15.0
Unidentified Geese	3 Ju	322 (353)	- (-)	11-13 Ju	-	-	-	-	-
Mallard	2 Ju	- (5)	- (-)	-	-	-	-	-	-
Pintail	1 Ju	- (1608)	37 (89)	5-12 Ju	9-15 Ju	L?	-	-	-
American Wigeon	7 Ju	- (8)	- (-)	7-10 Ju	-	-	-	-	-
Green-winged Teal	1 Ju	- (3)	- (-)	-	-	-	-	-	-
Shoveler	5 Ju	- (8)	- (-)	-	-	-	-	-	-
Oldsquaw	28 Ma	2409 (3627)	396 (2252)	2-10 Ju	19-20 Ju	E	E	178.3	69.8
Steller's Elder	4 Ju	- (2)	- (-)	-	-	-	-	-	-
Spectacled Elder	6 Ju	18 (28)	2 (7)	9-10 Ju	9 Ju	E	E	0.7	0.5
Common Elder	30 Ma	740 (979)	12 (74)	4-10 Ju	24 Ju[e]	E	W[e]	27.0	4.0[e]
King Elder	30 Ma	490 (943)	15 (117)	7-13 Ju	21 Ju[e]	E	W[e]	13.4	3.3[e]
Unidentified Elders	2 Ju	286 (404)	70 (252)	9-14 Ju	19-20 Ju	E	E	6.8	10.0
Red-br. + Unid. Mergansers	10 Ju	- (1)	- (3)	-	20 Ju	-	-	-	-

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Species	First Observed[a]	Approximate Number Seen[b]		Periods of Peak Abundance		Predominant Migration Direction[c]		Peak Migration Rate (# Birds/h)[d]	
	(1977)	(1977)	(1978)	(1977)	(1978)	(1977)	(1978)	(1977)	(1978)
Unidentified Diving Ducks	1 Ju	530 (708)	60 (80)	1-11 Ju	24 Ju	E	W	27.8	20.0
Unidentified Ducks	31 Ma	1032 (1535)	50 (89)	1-11 Ju	22 Ju	E	W	84.5	8.3
Unidentified Waterfowl	5 Ju	166 (295)	- (-)	5-9 Ju	-	E	-	14.1	-
Rough-legged Hawk	6 Ju	- (2)	- (-)	-	-	-	-	-	-
Willow Ptarmigan	18 Ma	- (1)	- (-)	-	-	L	-	-	-
Rock Ptarmigan	28 Ma	- (7)	- (-)	-	-	L	-	-	-
Black-bellied Plover	1 Ju	6 (7)	- (-)	1 Ju	-	L	-	-	-
American Golden Plover	29 Ma	12 (19)	4 (7)	29 Ma-3 Ju	19 Ju	L	E	-	1.0
Killdeer	12 Ju	- (1)	- (-)	-	-	-	-	-	-
Unidentified Plovers	2 Ju	1 (2)	- (-)	-	-	-	-	-	-
Ruddy Turnstone	24 Ma	32 (48)	- (6)	29 Ma-9 Ju	-	L	L	-	-
Common Snipe	24 Ma	- (3)	- (-)	-	-	-	-	-	-
Rufous-necked Sandpiper	2 Ju	- (1)	- (-)	-	-	-	-	-	-
Pectoral Sandpiper	6 Ju	13 (37)	- (2)	7-12 Ju	-	L	L	-	-
Baird's Sandpiper	31 Ma	26 (934)	- (3)	3-7 Ju	-	L	L	-	-
Buff-breasted Sandpiper	-	- (-)	- (27)	-	-	-	L	-	-
Dunlin	29 Ma	18 (22)	- (4)	3-12 Ju	-	L	L	-	-
Sanderling	-	- (-)	- (7)	-	-	-	L	-	-
Semipalmated Sandpiper	1 Ju	8 (8)	- (3)	3 Ju	-	L	L	-	-
Red Phalarope	3 Ju	48 (103)	4 (17)	8-12 Ju	16-19 Ju	E	W	1.7	0.7
Northern Phalarope	5 Ju	- (5)	2 (5)	12-14 Ju	18 Ju	-	-	-	-
Unidentified Phalaropes	12 Ju	- (4)	- (12)	-	-	-	-	-	-
Unidentified Shorebirds	29 Ma	84 (136)	- (19)	29 Ma-11 Ju	-	E	L	2.6	-

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Species	First Observed[a]	Approximate Number Seen[b]		Periods of Peak Abundance		Predominant Migration Direction[c]		Peak Migration Rate (# Birds/h)[d]	
	(1977)	(1977)	(1978)	(1977)	(1978)	(1977)	(1978)	(1977)	(1978)
Pomarine Jaeger	28 Ma	233 (323)	21 (39)	28 Ma-6 Ju	6-7 Ju	E	E	18.7	25.4
Parasitic Jaeger	29 Ma	76 (106)	2 (15)	29 Ma	11 Ju	E	E	38.3	1.0
Long-tailed Jaeger	5 Ju	5 (11)	- (2)	11-14 Ju	-	E	-	0.2	-
Unidentified Jaegers	28 Ma	96 (155)	4 (15)	29 Ma-10 Ju	22 Ju	E	W[e]	13.1	0.7[e]
Glaucous Gull	17 Ma	280 (1162)	90 (733)	9-13 Ju	9-22 Ju	E	E	4.3	6.5
Herring/Thayer's Gull	2 Ju	- (9)	- (1)	-	-	-	-	-	-
Mew Gull	13 Ju	- (2)	- (-)	-	-	-	-	-	-
Sabine's Gull	7 Ju	4 (6)	13 (41)	7-12 Ju	7-20 Ju	E	W[e]	0.1	1.5[e]
Black-legged Kittiwake	9 Ju	3 (3)	- (1)	9 Ju	-	E	-	0.2	-
Unidentified Gulls	1 Ju	14 (19)	- (-)	9-13 Ju	-	E	-	0.7	-
Arctic Tern	6 Ju	18 (60)	15 (46)	10-13 Ju	16-21 Ju	E	E	0.4	0.9
Snowy Owl	11 Ju	- (1)	- (1)	-	-	-	-	-	-
Short-eared Owl	31 Ma	- (4)	- (-)	-	-	-	-	-	-
Horned Lark	6 Ju	- (2)	- (-)	-	-	-	-	-	-
Unidentified Swallows	1 Ju	3 (3)	- (-)	1-12 Ju	-	E	-	-	-
Black-billed Magpie	27 Ma	- (3)	- (-)	27-28 Ma	-	L	-	-	-
Common Raven	25 Ma	- (9)	- (-)	-	-	L	-	-	-
Savannah Sparrow	2 Ju	- (3)	- (-)	-	-	L	-	-	-
White-crowned Sparrow	24 Ma	- (2)	- (-)	24 Ma-3 Ju	-	L	-	-	-
Dark-eyed Junco	29 Ma	- (1)	- (-)	-	-	L	-	-	-
Unidentified Redpolls	31 Ma	- (15)	- (-)	-	-	L	-	-	-
Snow Bunting	17 Ma	- (102)	- (5)	-	-	L	L	-	-
Lapland Longspur	27 Ma	- (100)	- (1)	-	-	L	L	-	-

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[a] Dates of first observation during 1977 include incidental records as well as records during migration watches. During 1978, systematic migration watches were not begun until 6 June; hence many dates of first arrival were not recorded. During 1977 there were no systematic watches after 15 June.

[b] Numbers to left of parentheses are total birds seen migrating in the predominant direction during the period of peak abundance. Numbers in parentheses are total birds seen (migrants and others) during all spring migration watches and during casual observations (up to 25 June). Numbers are approximate because some casual observations were not recorded and because of difficulties with repeated sightings of local birds.

[c] E = East, W = West, L = Local.

[d] Peak migration rate is number of migrants seen per hour during the date of peak movement.

[e] Unexpected direction, perhaps attributable to small sample size and/or late date of initiation of study in 1978.

[f] On 27 June, 50 additional snow geese flew west.

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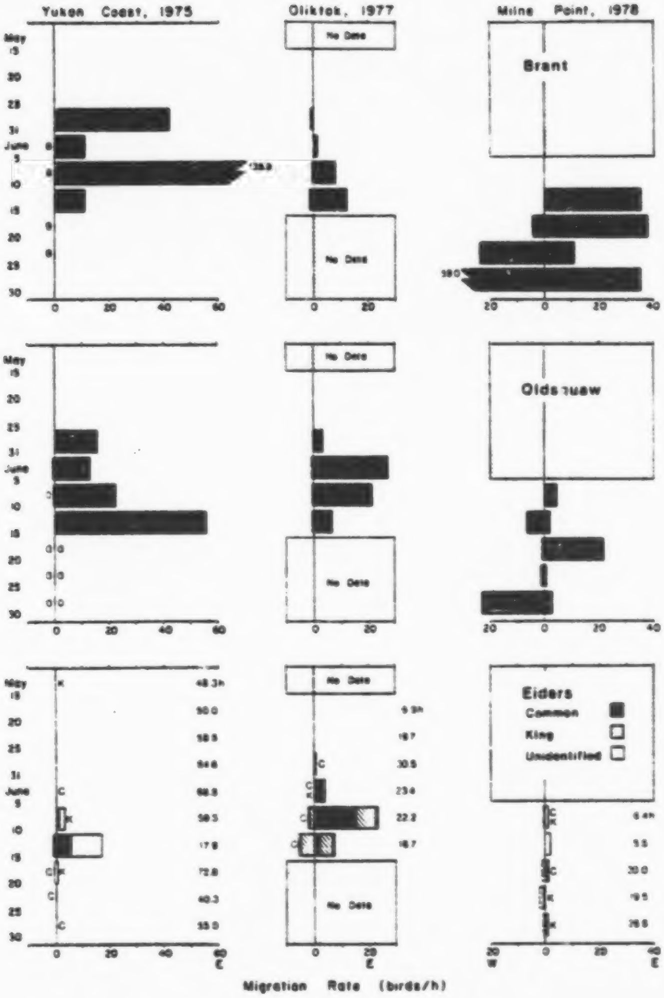

Figure 5. Rates of eastward (right of baseline) and westward (left of baseline) migration of brant, oldsquaws and eiders by 5-day period in spring. Birds more than 3 km offshore or 1 km inland not considered. Letters mean 'seen but rate too low to be plotted'. Stippled areas indicate dates with no observations. The number of hours of observations in each 5-day period is given in the 'eider' section (periods with visibility less than 3 km omitted). Yukon data (1975) recalculated from data of Johnson et al. (1975) and Richardson et al. (1975).

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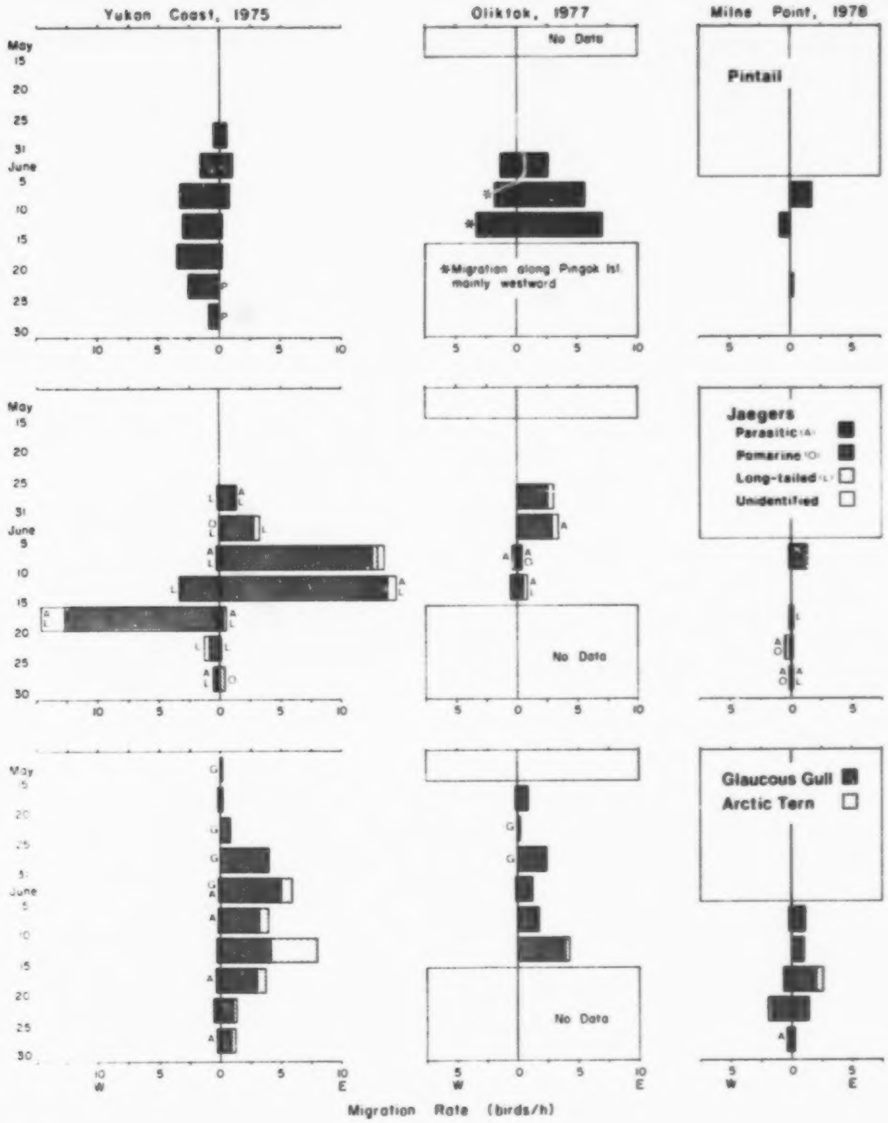

Figure 6. Rates of eastward (right of baseline) and westward (left of baseline) migration of pintails, jaegers, glaucous gulls and arctic terns by 5-day period in spring. Plotted as in previous diagram but with expanded horizontal scale.

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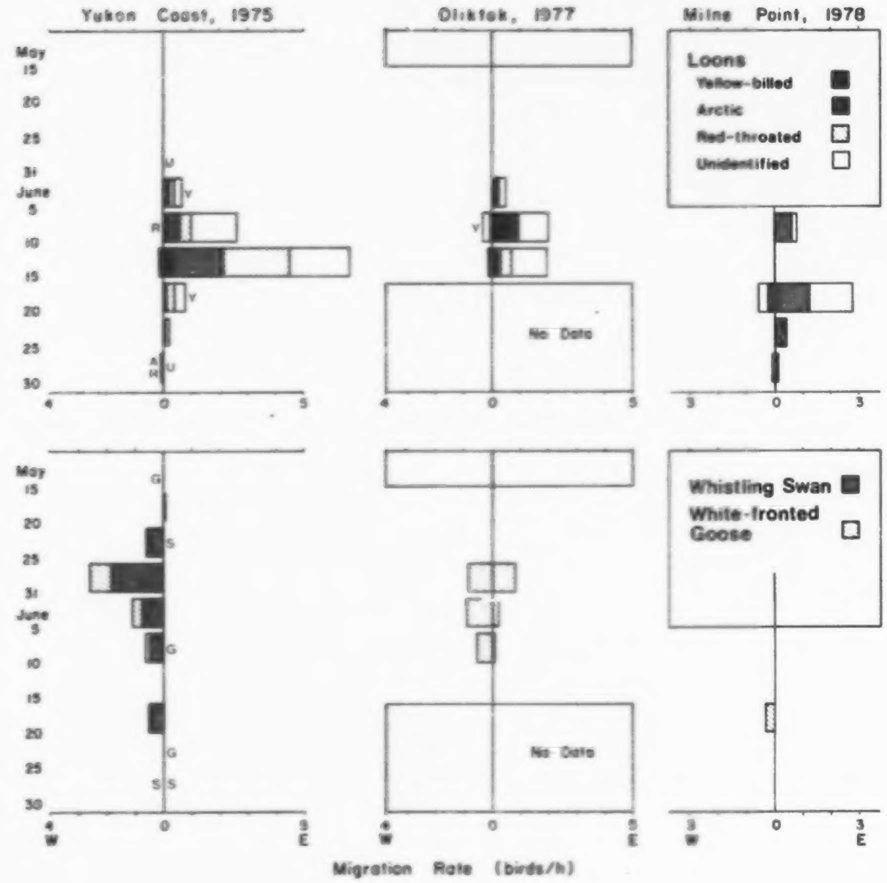

Figure 7. Rates of eastward (right of baseline) and westward (left of baseline) migration of loons, whistling swans and white-fronted geese by 5-day period in spring. Plotted as in previous diagram but with further expansion of horizontal scale.

(Table 2). Results from migration watches along the Yukon coast in 1975 (9 May-9 July) were similar to those from Simpson Lagoon in 1977 (Fig. 5-7). The first glaucous gulls were moving east by 11 May 1975 and the first white-fronted geese and whistling swans were seen in mid-May. The only eiders seen along the Yukon coast in May 1975 were four king eiders flying east on 13 May. Thus our data are consistent with the opinion (Brooks 1915; Flock 1973; Johnson et al. 1975) that many common and king eiders that migrate east past Point Barrow and appear off Banks Island in May fly far offshore rather than along the coast.

The period of peak visible migration through the Simpson Lagoon area in the spring of 1977 was the first two weeks of June. The most abundant species of migrants at this time were brant, oldsquaw and eiders (common and king), all of which migrate eastward through the Beaufort Sea area in spring. These species were first seen on 31, 28, 30 and 30 May, respectively; peak eastward migration occurred in the third, first, second and second 5-day periods of June, respectively (Fig. 5). The timing of these migrations was generally similar to that in 1975 along the Yukon coast, but in 1975 peak brant migration was slightly earlier whereas peak oldsquaw and eider migration was slightly later (Fig. 5). Interpretation of the 1978 migration is hindered by the fact that observations in Simpson Lagoon did not begin until 6 June, but the migrations of both brant and oldsquaw seemed later than in 1975 and 1977, and few migrating eiders were seen. By mid-June in both 1977 and 1978, numbers of eiders moving west became similar to numbers flying east; we assume that many of these mid-June sightings represented local movements of eiders.

The timing of spring migration of other common (but not abundant) waterbird species is shown in Fig. 6 and 7; note the expanded scales in relation to the scale of Fig. 5. Loons (3 species), jaegers (3 species), glaucous gulls and arctic terns were the main eastbound migrants in this group. Most jaegers move east from late May to mid June, and most glaucous gulls (despite the early first arrival dates) also migrate in this period. Most of the loons, arctic terns and red phalaropes seen migrating east along the coast pass in early and mid June, along with various less numerous migrants such as Thayer's gulls and Sabine's gulls.

The only common waterbird species that appeared to migrate westward in significant numbers over Simpson Lagoon in the spring of 1977 were pintails and white-fronted geese. Both of these species commonly engaged in local flights, and it was often impossible to separate local flights from migration. This confusion no doubt accounts for the apparent similarity in rates of westbound and eastbound 'migration' of these species during 1977 (Fig. 6, 7). Along the Yukon coast in 1975, these two species and also whistling swans were more consistently westbound. Little westward return movement of pomarine or parasitic jaegers was evident at Simpson Lagoon in mid to late June of 1977 or 1978, unlike the situation along the Yukon coast in 1975 (Fig. 6).

The total amount of visible westward migration along both Simpson Lagoon and the Yukon coast was much less than the amount of visible eastward migration. We have no definite explanation for the large numbers of westward migrants detected by radar, but we suspect that shorebirds were often involved. Shorebirds are abundant summer residents of the North Slope, but few are seen migrating along the coast. It is known that during migration they often fly at high altitudes and on a broad front, and thus are virtually invisible to field observers (Richardson 1979).

Flight Paths. The Oliktok radar showed that neither eastward nor westward migration was restricted to the coastal area; instead, both occurred across a broad front. Migrations in both directions were detected almost continuously throughout the peak of the spring migration season not only near the coast, but also as far as 20 km inland and 20 km offshore (Fig. 3, 4). In fact, on most occasions at least a few eastbound and westbound migrants were detectable as far as 50 km inland and offshore (Fig. 8). The modal direction of 'eastbound' migrants was often slightly north of east (080°) far inland and slightly south of east (100°) offshore (Fig. 8). The modal direction of 'westbound' migrants was usually slightly north of west (280°) in all areas. Figures 9 and 10 show examples of the actual paths of individual birds and flocks across the radar coverage area.

Even though eastward migration occurred continuously and westward migration occurred nearly continuously throughout the peak migration period, the amount of migration varied from time to time (Fig. 3, 4). These variations were more or less synchronous overland south of Oliktok, in and

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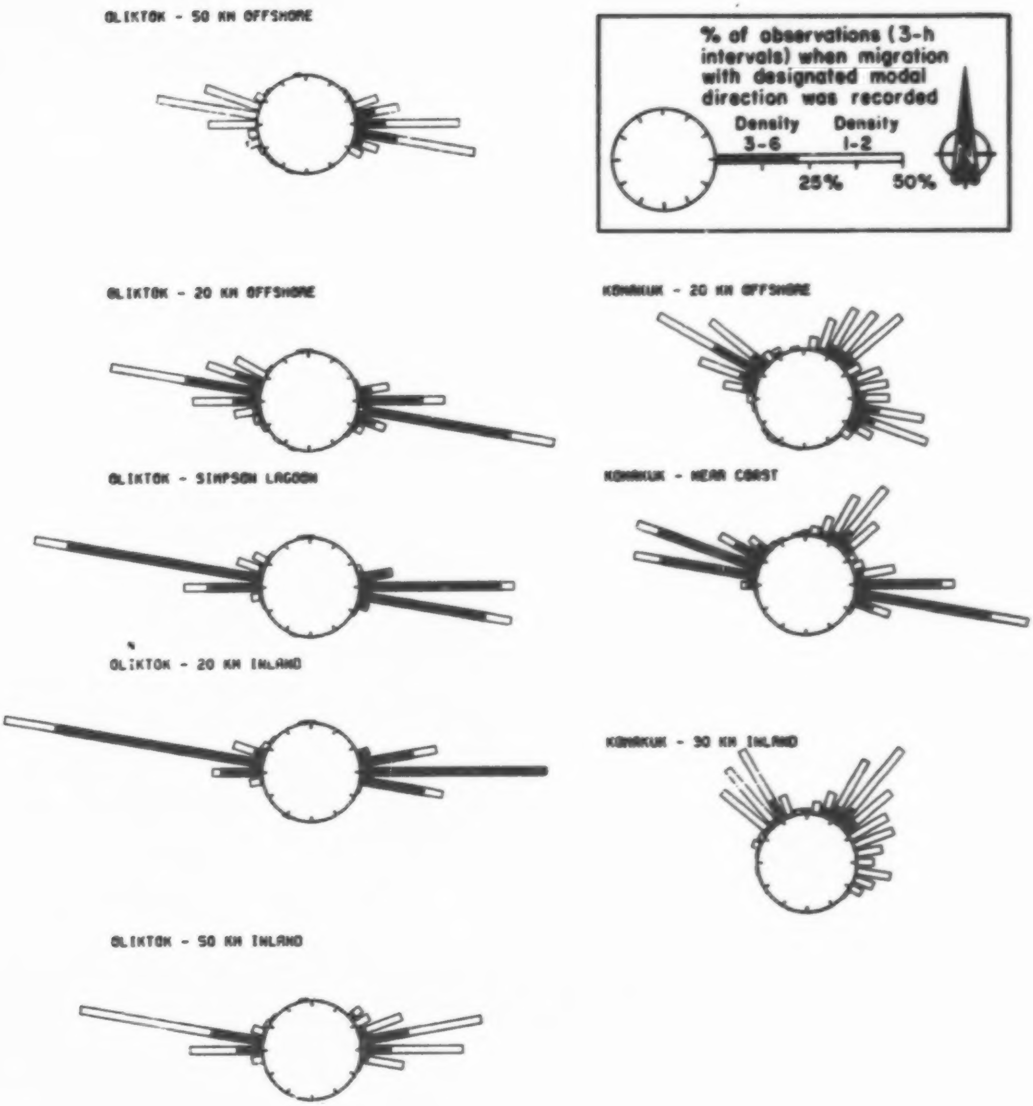

Figure 8. Frequency of migratory movements in various directions, based on radar data from Oliktok, Alaska (1977), and Komakuk, Y.T. (1975), 9 May-20 June.

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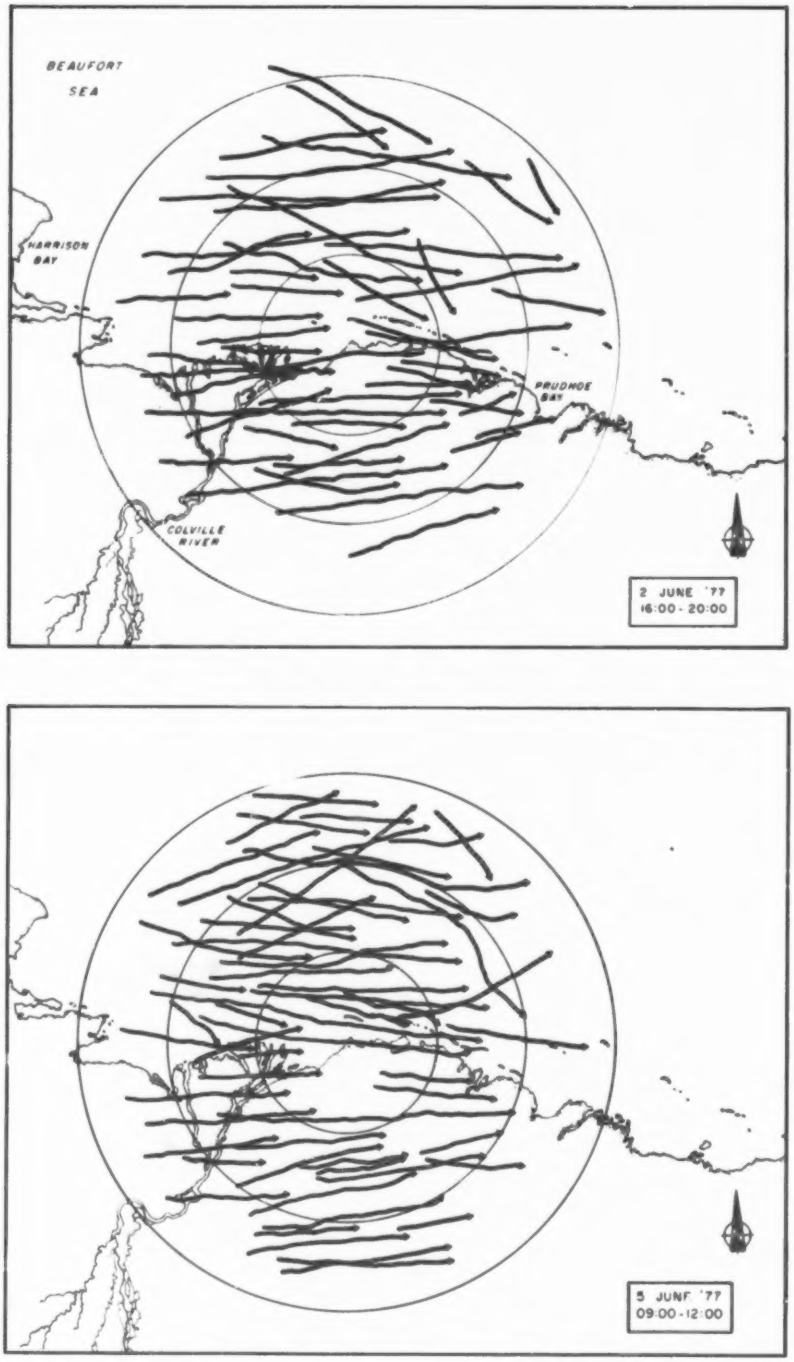
BEAUFORT SEA
HARRISON BAY
PRUDHOE BAY
COLVILLE RIVER
2 JUNE '77
16:00 - 20:00
5 JUNE '77
09:00 - 12:00

Figure 9. Flight paths of samples of the birds migrating east over the North Slope and Beaufort Sea on 2 and 5 June 1977. Outer circle has radius 75 km; centered at Oliktok radar. On 2 June, oldsquaws were by far the most abundant migrants seen flying east. On 5 June, brant, pintails, oldsquaws and jaegers were the main eastbound species.

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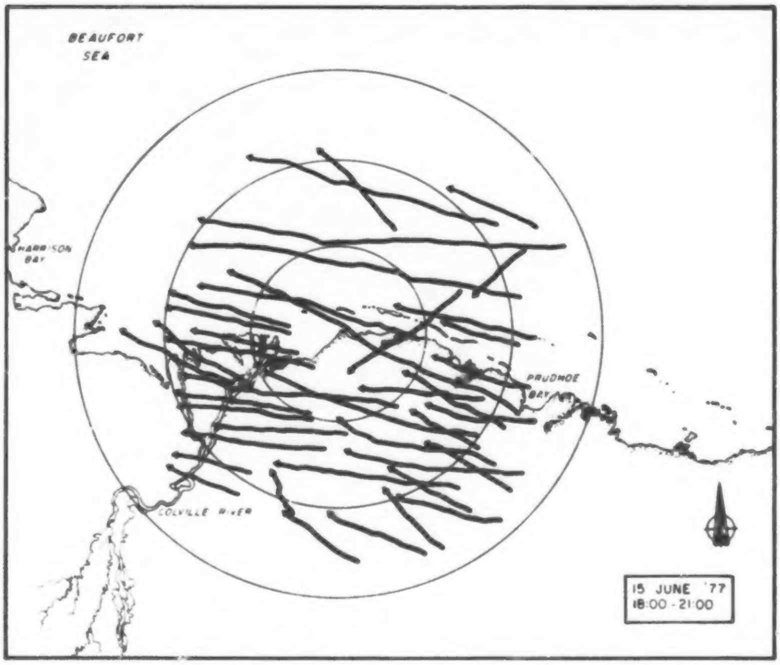
BEAUFORT SEA
HARRISON BAY
PRUDHOE BAY
COLVILLE RIVER
15 JUNE '77
18:00 - 21:00

Figure 10. Flight paths of a sample of the birds migrating west over the North Slope and Beaufort Sea on 15 June 1977. A few brant and king eiders were the only species seen to fly west on this date.

near Simpson Lagoon, and offshore. Migration densities in each of these three areas were closely correlated with densities in the other areas (Fig. 11, 12).

The above results from the Oliktok/Simpson Lagoon area differ in several ways from results obtained farther east, along the Yukon coast, by Richardson et al. (1975):

1. In the Yukon, numerous migrants were detected flying northeast. These birds approached from interior Alaska, crossed the North Slope (which is only a few kilometers wide here), and departed seaward (Fig. 8). Similar flights were not evident in the Oliktok area.
2. In the Yukon, few migrants were detected 20-50 km inland, and densities there were not closely correlated with densities near the coast and offshore (Fig. 11, 12). The area 20-50 km inland from the Yukon coast is mountainous, whereas the area 20-50 km inland from Oliktok is within the North Slope.
3. The main axis of 'east-west' migration along and north of the Yukon coast was ESE-WNW, whereas that along and north of the Alaskan coast near Oliktok was closer to east-west (Fig. 8).

The Oliktok radar indicated that spring migrants did not concentrate to any major degree along the coast, along the barrier islands, or anywhere else within the radar coverage area. Some birds observed on radar changed course to follow mainland or island shorelines, and radar often showed more birds over the barrier island-lagoon system than inland or offshore. However, radar never showed an intense, narrow stream of birds along the mainland coast, lagoon, islands or elsewhere. This situation contrasts with that found along the coast of the northern Yukon in the spring of 1975 (Richardson et al. 1975), where the Komakuk radar often showed a narrow, concentrated stream along the coast, and where coastal visual observations recorded more spring migrants than were seen in this study. For both eastward and westward migration, the degree of coastal concentration was significantly greater near Komakuk, Y.T., than near Oliktok (Table 3).

We suspect that there are three main reasons for the more diffuse spring migration in the Simpson Lagoon area:

1. The North Slope is broad south of Simpson Lagoon, but becomes narrower to the east and is narrowest south of Komakuk. Birds migrating east (or west) along the North Slope would be channeled toward the coast as they approached the Komakuk area.

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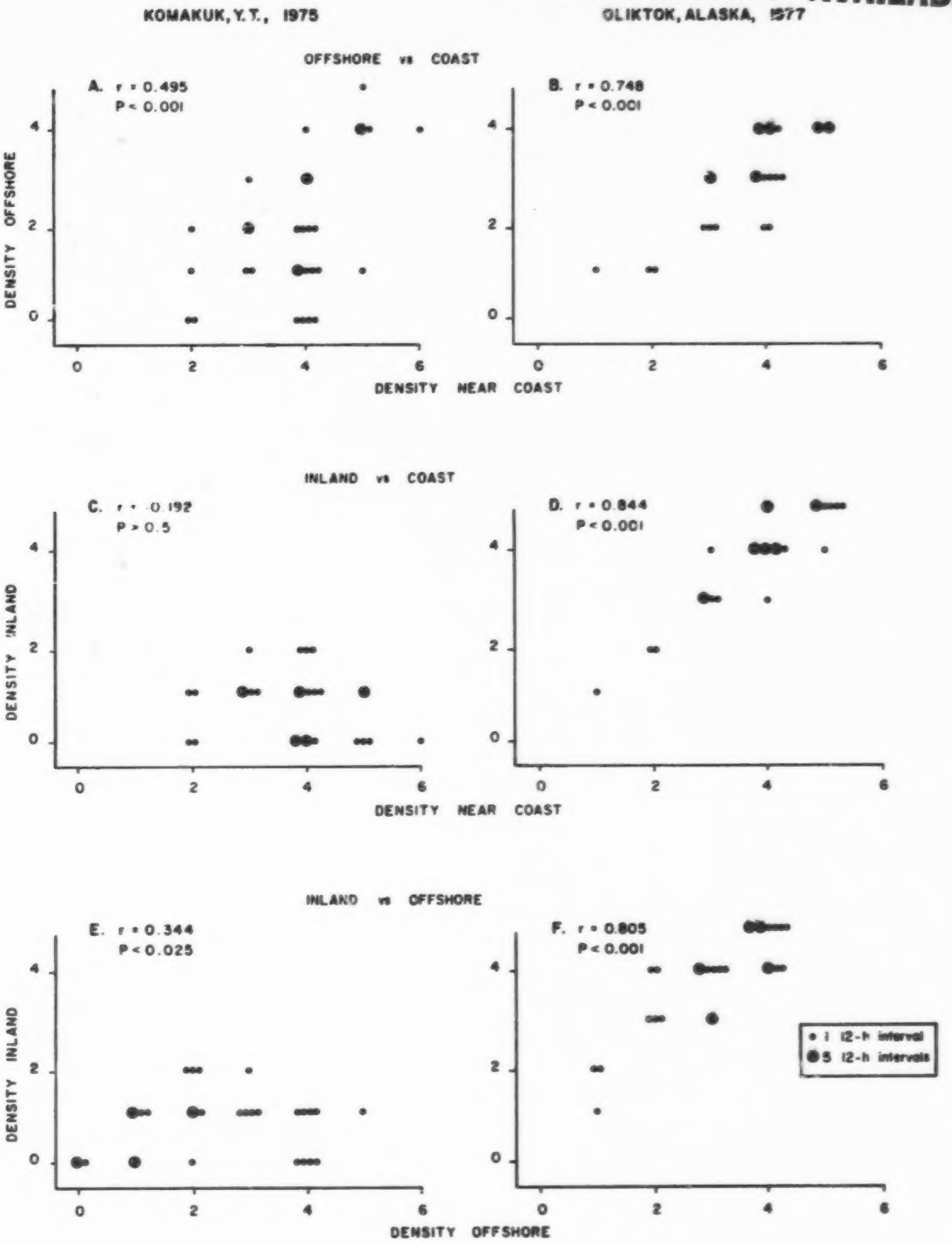

Figure 11. Relative amounts of eastward migration detected by radar offshore, near the coast, and inland, 25 May - 20 June. Migration rates measured on the 0 to 8 ordinal scale twice each day (09:00 and 21:00 LST). Spearman rank correlation coefficients and 1-sided significance levels are given.

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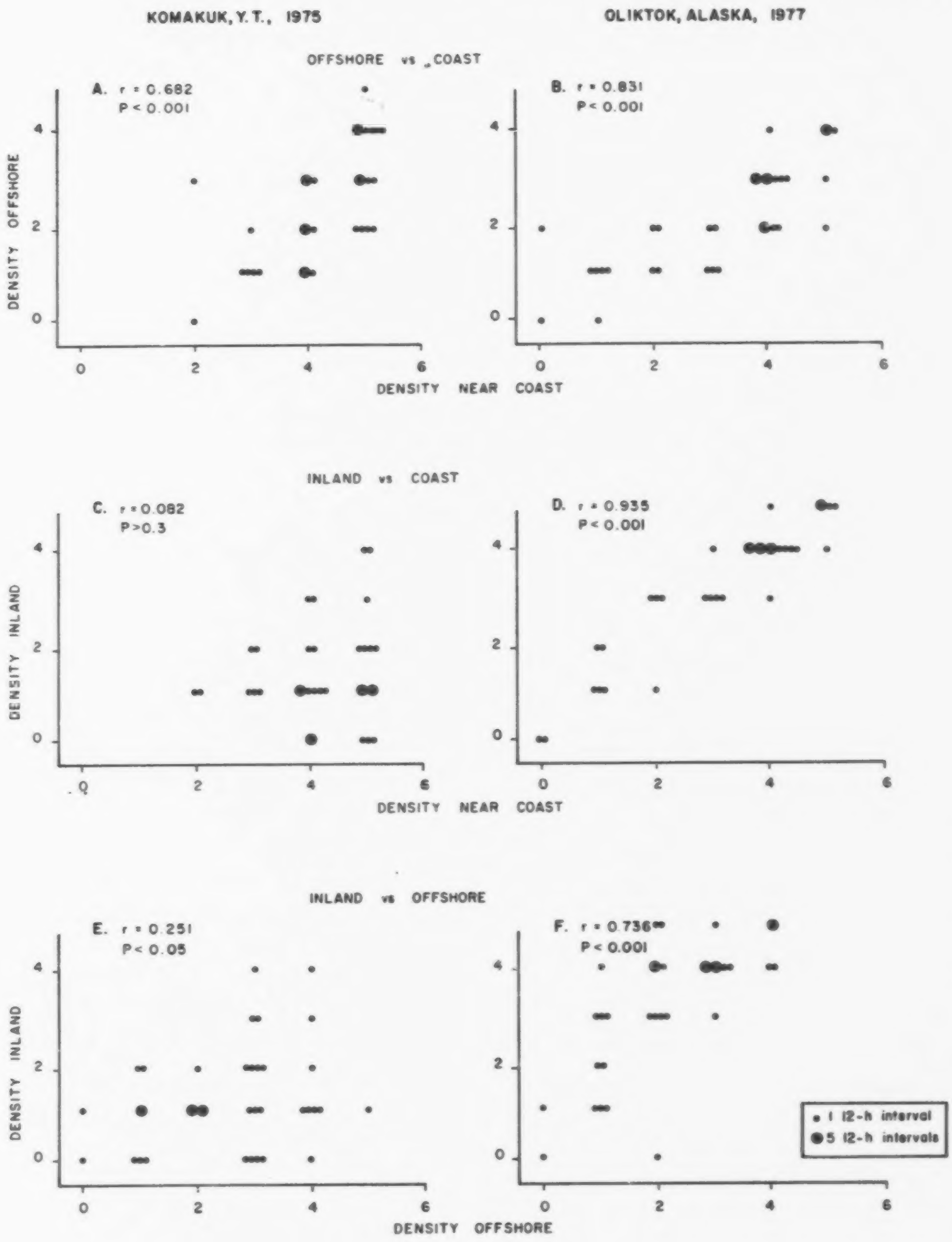

Figure 12. Relative amounts of westward migration detected by radar offshore, near the coast, and inland, 25 May - 20 June. Plotted as in previous figure.

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Table 3. Comparison of tendency of spring migrants to concentrate along the coast near Komakuk, Y.T. (1975), and Oliktok, Alaska (1977). Based on radar observations at 12-h intervals (09:00 and 21:00 LST), 25 May-20 June.

Density near Coast[a]	Median Density Inland or Offshore		No. 12 h Periods		P[b] (2 sided)	z[c]
	1975	1977	1975	1977		
COAST vs. INLAND						
Eastward Migration						
2	½	2	4	2	0.134	1.50
3	1	3	8	8	<0.001	>3.30
4	½	4	22	22	$<10^{-5}$	5.89
5	1	5	8	10	<0.002	>3.09
2-5	-	-	-	-	$<10^{-5}$[e]	>7.39[d]
Westward Migration						
2	1	3	2	4	0.266	1.11
3	1	3	5	5	0.008	2.65
4	1	4	18	21	$<10^{-5}$	5.68
5	1	5	20	8	$<10^{-4}$	4.16
2-5	-	-	-	-	$<10^{-5}$[e]	7.46[d]
COAST vs. 20 km OFFSHORE						
Eastward Migration						
2	½	1	4	2	0.800	0.25
3	2	3	8	8	0.050	1.96
4	1	3½	22	22	$<10^{-5}$	4.58
5	4	4	8	10	1.000	0.00
2-5	-	-	-	-	$<10^{-5}$[e]	4.67[d]
Westward Migration						
2	1½	1½	2	4	1.000	0.00
3	1	1	5	5	0.690	0.40
4	2	3	18	21	0.008	2.67
5	3	4	21	8	0.322	0.99
2-5	-	-	-	-	0.006[e]	2.76[d]

[a] Densities 0, 1 and 6 occurred too rarely to permit statistical analysis.

[b] Mann-Whitney U test of null hypothesis that, with a given density near the coast, the density inland (or offshore) was the same at Oliktok in 1977 as at Komakuk in 1975.

[c] z-score [from normal (0, 1) distribution] corresponding to P value. All z-scores were positive or zero.

[d] Pooled z-score, based on weighted z method (Rosenthal 1978):

$$\text{Pooled } z = \Sigma\, df_i\ z_i \;/\; [\,\Sigma\, (df_i)^2]^{\frac{1}{2}}, \quad \text{where } df_i = N_{1975} + N_{1977} - 2.$$

[e] Overall P value for test of null hypothesis that the degree of coastal concentration was the same at Oliktok in 1977 as at Komakuk in 1975; based on the pooled z-score.

2. The coast in the Simpson Lagoon area is probably less effective as a 'leading line' for migrants. The coast near Komakuk, Y.T., is an almost linear feature, whereas the coast in the Simpson Lagoon area is more irregular because of the presence of bays and points. Furthermore, the coast near Komakuk is the only prominent leading line, whereas near Oliktok the barrier islands may form a second leading line.

3. There is no open water along the coast in the Simpson Lagoon area during May or early June. Even after river water overflows onto the ice in early June, access to food resources below the landfast ice remains blocked.

Visual observations during the 6-14 June 1977 period provided information about routes of particular species across the Simpson Lagoon area. During that period migration was observed from

1. the mainland looking north over the ice and river runoff to mid-lagoon,
2. Pingok Island looking south to mid-lagoon, and
3. Pingok Island looking north over the frozen Beaufort Sea.

These observations showed that almost all brant flying east over the Simpson Lagoon area were over the southern half of the lagoon or the mainland (Table 4, columns E-G). Oldsquaws and eiders were also most numerous over the southern part of the lagoon, but these seaducks, unlike brant, also flew in considerable numbers over the northern side of the lagoon and the Beaufort Sea. Among the less abundant species, eastbound red phalaropes, pomarine jaegers and arctic terns were commonly seen over both the south and north side of the lagoon, but not over the sea. Eastbound loons and glaucous gulls were distributed on a broad front across the lagoon and also the nearshore Beaufort Sea (Table 4). These results, in combination with the low numbers of most waterbird species seen migrating over the Simpson Lagoon area in spring (see below), suggest that a variety of species may participate in the broad front eastward migration detected by radar offshore over the Beaufort Sea and inland over the North Slope.

Numbers. In this section we estimate numbers of waterbirds that migrate at low altitudes (i.e., visible to field observers) along the south coast of the Beaufort Sea in spring. Estimates for the spring of 1977 are derived in Table 4. Observations at Simpson Lagoon in spring 1978 began too late to permit meaningful estimates. However, the table does include estimates of numbers migrating along the Yukon coast during

Table 4. Estimated total numbers of waterbirds migrating along the south coast of the Beaufort Sea in spring (9 May-25 June), 1975 and 1977. The main estimates are in columns D and I.[a] Table includes all loons, jaegers and terns, specifically identified phalaropes, and all species of waterfowl for which the net number of migrants seen from the mainland (column B) exceeded 10 in either year.

Species (Main direction of migration)	Year	Net No. Seen from Mainland at Dist. from Shore (km)		Estimated Net No. Passing, -1 to +3 km from Shore		Net Rate (birds/h) on 6-14 June 1977 over			Est. Net No. Passing, 9 May-25 June 1977	
		-1 to +3 (A)	All (B)	16 May-15 June (C)	9 May-25 June (D)	S half Lagoon (E)	N half Lagoon (F)	S edge of Sea (G)	Lagoon + Pingok Is. (H)	Lagoon + Is. + Sea (I)
Yel.-bil. Loon	1975	15	15	46	52					
(E)	1977	18	18	96	109	0.32	0.15	0.07	161	187
Arctic Loon	1975	77	77	286	295					
(E)	1977	11	11	65	67	0.29	0.38	0.20	155	200
Red-thr. Loon	1975	103	104	362	402					
(E)	1977	6	6	43	48	0.16	0.10	0.12	79	116
Unid. Loons	1975	187	196	479	546					
(E)	1977	45	157	282	321	0.96	1.53	0.92	834	1,140
All Loons	1975	382	392	1,173	1,295					
(E)	1977	80	192	486	537	1.73	2.17	1.31	1,210	1,617
Whistling Swan	1975	291	313	458	512					
(W)	1977	(-2)[b]	(-2)	(-11)	(-12)	0.05	0	0	(-12)	(-12)
Canada Goose	1975	30	30	51	51					
(W)	1977	0	0	0	0	0	0	0	0	0

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Species (Main direction)	Year	Net Seen, Mainland		Net Estim., Mainland		Birds/h, 6-14 June 1977			Net Estim., 9 May-25 June	
		-1 to +3 km (A)	All (B)	16 May-15 June (C)	9 May-25 June (D)	S half Lag. (E)	N half Lag. (F)	Sea (G)	Lag. + Is. (H)	Lag. + Is. + Sea (I)
Brant	1975	12,546	14,517	25,953	25,946					
(E)	1977	334	424	2,141	2,140	9.14	(-0.10)	(-0.17)	2,116	2,076
Wh.-fr. Goose	1975	103	166	178	184					
(W)	1977	28^c	15^c	146	151	0.32	0.08	(-0.02)	187	176
Snow Goose (W)	1975	19^c	27^c	36	36					
(E)	1977	2	10	11	11	0.05	0.31	0	74	74
Pintail	1975	532	528	637	1,318					
(W)	1977	(-183)^c	(-195)^c	(-1092)	(-2259)	(-4.05)	5.95	1.66	1,061	1,985
Oldsquaw	1975	4,416	4,778	13,026	12,998					
(E)	1977	1,323	2,059	7,078	7,063	15.16	6.21	3.39	9,955	11,534
Common Eider	1975	124	209	577	562					
(E)	1977	426	611	2,335	2,274	9.67	2.89	2.55	2,953	3,552
King Eider	1975	21	21	84	101					
(E)	1977	168^c	191^c	904	1,087	3.54	2.43	1.29	1,831	2,226
Unid. Eider	1975	300	302	1,626	1,595					
(E)	1977	9^c	101	32	31	0.21	1.07	1.31	187	378
All Eiders[d]	1975	445	532	2,287	2,258					
(E)	1977	599	899	3,250	3,209	13.37	6.54	5.34	4,779	6,060

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Page 3...

Species (Main direction)		Year	Net Seen, Mainland		Net Estim., Mainland		Birds/h, 6-[illegible] June 1977			Net Estim., 9 May-25 June	
			-1 to +3 km (A)	All (B)	16 May-15 June (C)	9 May-25 June (D)	S half Lag. (E)	N half Lag. (F)	Sea (G)	Lag. + Is. (H)	Lag. + Is. + Sea (I)
All Scoters		1975	482	482	(-42)	1,326					
(W)		1977	0	0	0	0	0	0	0	0	0
Red-br. Merganser		1975	12	12	11	22					
(E)		1977	0	0	0	0	0	0	0	0	0
Red Phalarope		1975	118	118	250	254					
(E)		1977	10[c]	10[c]	76	77	0.45	0.36	(-0.02)	138	134
Nor. Phalarope		1975	24[c]	24[c]	43	79					
(E)		1977	0	0	0	0	0	(-0.03)	0.02	—[e]	—[e]
Pomarine Jaeger	(E)[f]	1975	1,262	1,441	3,597	3,632					
	(W)[f]	1975	1,011	1,190	417	2,001					
	(E)	1977	140	200	677	684[g]	(-0.11)	0.61	(-0.12)	> 684[h]	> 684[h]
Parasitic Jaeger	(E)[f]	1975	30	31	62	66					
	(W)[f]	1975	23	27	2	38					
	(E)	1977	5	82	30	32[g]	0.08	(-0.03)	0.10	22	61
Long-t. Jaeger		1975	29	44	47	53					
(E)		1977	1	1	7	8	0.03	0.03	0.02	16	23
Unid. Jaeger	(E)[f]	1975	96	184	222	235					
	(W)[f]	1975	161	370	10	292					
	(E)	1977	32	82	169	179[g]	0.13	0.26	(-0.02)	522	489
All Jaegers	(E)[f]	1975	1,428	1,711	3,952	4,015					
	(W)[f]	1975	1,206	1,598	453	2,361					
	(E)	1977	178	365	883	897[g]	0.13	0.87	(-0.02)	> 1,244[h]	> 1,257[h]

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170

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Page 4...

Species (Main direction)	Year	Net Seen, Mainland		Net Estim., Mainland		Birds/h, 6-14 June 1977			Net Estim., 9 May-25 June	
		-1 to +3 km (A)	All (B)	16 May-15 June (C)	9 May-25 June (D)	S half Lag. (E)	N half Lag. (F)	Sea (G)	Lag. + Is. (H)	Lag. + Is. + Sea (I)
Glaucous Gull	1975	1,170	1,213	2,075	2,466					
(E)	1977	202	239	1,210	1,438	2.48	1.25	1.98	2,164	3,313
Thayer's + Herring	1975	19	19	42	37					
Gull (E)	1977	1^c	1^c	6	5	0.03	0	0	5	5
Sabine's Gull	1975	35	35	72	73					
(E)	1977	2	2	11	11	0.05	0	0	11	11
Arctic Tern	1975	236	250	664	787					
(E)	1977	10	11	65	77	0.27	0.18	0	129	129

[a] Explanation of columns:

A,B. Number of migrants seen moving in main direction, less number seen moving in opposite direction, during systematic watches from Komakuk and Clarence Lagoon (1975) or Oliktok (1977) considering only the periods when the visibility was at least 3 km. Birds flying 030-150° were considered eastbound; 210-330° westbound. In 1975, many birds were undoubtedly counted twice, once at Clarence Lagoon and once at Komakuk. The few cases in which (B)<(A) are those in which the majority of birds distant from the observer were flying in the 'opposite' direction.

C. Net 'birds/hour' values in each 5 to 7 day period (Figures 5, 6, 7) multiplied by durations of those periods and then summed.

D. For 1975, same method as (C). For 1977, when there were no observations during the 9-15 May and 16-25 June periods, estimated as $(C_{77})(D_{75})/C_{75}$.

E. Based on 37.5 h of observation at Oliktok, considering birds between 1 km inland and 3 km offshore (mid-lagoon).

F. Based on 39.2 h of observation from the south side of Pingok Island, considering birds from 3 km offshore (mid-lagoon) to 1 km behind the observer (roughly the north side of Pingok Island).

G. Based on 40.4 h of observation from the north side of Pingok Island, considering birds from 0.1 km inland to 3 km seaward over the Beaufort Sea.

H. Calculated as (D) (E + F)/E.

I. Calculated as (D) (E + F + G)/E.

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[b] Parenthetical negative values represent net migration in direction opposite to the 'main' direction stated beside species name.

[c] Number seen migrating in predominant direction was less than 3X number in opposite direction.

[d] 'All eiders' includes the few Spectacled and Steller's Eiders seen in 1977.

[e] Not calculable but near zero.

[f] In 1975, eastward and westward migrations of these jaegers were treated separately -- not converted into net figures.

[g] Calculated from column (C) using only the eastbound totals from 1975.

[h] Not calculable because most eastward migration of Pomarine Jaegers took place before 6 June in 1977.

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spring 1975, based on reanalysis of the original data of Johnson et al. (1975) and Richardson et al. (1975). The approach used was to (1) calculate migration rates (birds per hour) for each species within each 5-day period of the spring (Fig. 5-7), (2) extrapolate these rates to all hours in the respective periods, and (3) sum the estimates across all periods. Only the data collected during watches with visibility at least 3 km were used, and birds more than 3 km offshore or 1 km inland were not considered. Numbers flying over Simpson Lagoon in the 9-15 May and 16-25 June 1977 periods, when we made no observations, were estimated using the 1975 Yukon data (see Table 4, footnote for column D).

Brant, oldsquaws, common eiders and king eiders were the most abundant eastbound waterbird migrants at Simpson Lagoon in 1977. However, their estimated numbers were very low (2116, 9955, 2953 and 1831, respectively) relative to approximate numbers occurring in the Beaufort Sea area ($<10^5$, 10^6, $>10^5$ and 10^6, respectively--Thompson and Person 1963; Johnson 1971; Bellrose 1976; Timson 1976). Estimated numbers migrating along the Yukon coast in spring 1975 were much higher in the case of brant (25,946), similar in the case of oldsquaw (12,998), and even lower in the case of eiders (562 common, 101 king, 2258 total). All of these values are imprecise because of (1) our undoubted failure to detect some birds that flew by during migration watches, (2) the fact that birds classed as 'possible migrants' were not considered, and (3) the various extrapolations used. Nonetheless, it is clear that only small proportions of the brant, oldsquaws and eiders that occur in the Beaufort Sea area migrated at low altitude through Simpson Lagoon in the spring of 1977. Incomplete data from 1978 (Fig. 5) suggest that somewhat more brant may have passed over the lagoon that year, but there was no evidence of larger numbers of oldsquaws or eiders in spring 1978.

Many brant are known to migrate north or northeast through interior Alaska rather than around the coast (Cade 1955; Irving 1960). Few eiders appear to migrate through the interior of Alaska, and the number of oldsquaws doing so is unknown. Most common and king eiders and perhaps most oldsquaws appear to migrate east across offshore portions of the Beaufort Sea rather than along the coast of northern Alaska or through the interior.

Numbers of loons migrating through Simpson Lagoon in spring are of special interest because it is possible that most of the arctic and yellow-billed loons nesting in the North American arctic migrate around the Alaskan coast (Palmer 1962) and thus through the Simpson Lagoon area. However, only 1210 loons were estimated to have flown through Simpson Lagoon in spring 1977, and the estimate for the Yukon coast in spring 1975 was similar (1295). Estimates for the individual loon species are unreliable because of the large number of loons not identified to species. Total numbers of arctic and yellow-billed loons nesting in the North American arctic are unknown, but it is clear that only small proportions of these birds migrate at low altitude through Simpson Lagoon in spring. In contrast to our estimate of only 1210 loons passing through Simpson Lagoon in spring, Timson (1976) estimated that about 50,000 flew west past Point Barrow during the 27 August to 16 September 1975 period.

Many pomarine jaegers migrate along the coast in spring, but few parasitic or long-tailed jaegers do so (Table 4). Long-tailed jaegers and apparently also some pomarine jaegers migrate north through interior Alaska (Kessel and Cade 1958; Irving 1960; Dean et al. 1976), but the route of most parasitic jaegers to the North Slope is unknown. Our figures may underestimate the amount of eastward migration of parasitic jaegers near the coast; we saw flocks of 39 and 37 moving east overland 2-4 km south of Oliktok Point on 29 May 1977.

Glaucous gulls migrate along the coast at only low to moderate rates, but for a prolonged period (Fig. 6). Total numbers moving east through Simpson Lagoon in spring 1977 were estimated as 2164; the estimate for the Yukon in spring 1975 was similar (2466).

No other gulls migrate in large numbers through Simpson Lagoon. Numbers of Thayer's gulls migrating east along the coast in spring are extremely low. Clearly this species does not migrate along the north coast of Alaska while en route from its Pacific wintering grounds to its breeding areas in the Canadian Arctic. Estimated numbers of Sabine's gulls were only slightly higher. Arctic terns were not abundant at Simpson Lagoon in the spring of 1977 (129 estimated) but were more numerous along the Yukon coast in 1975 (787 estimated).

The above estimates and the Oliktok radar data are consistent with one another in suggesting that the north coast of Alaska forms the spring migration route of only a minority of the waterbirds using the Beaufort Sea. Farther east, where the North Slope is narrower, the spring migration routes of certain species such as brant and arctic terns appear to be narrower and more closely concentrated along the coast.

Utilization of Study Area. Most waterbirds that migrate through the Simpson Lagoon area during spring appear to fly over the area without stopping. However, some waterfowl land at meltwater pools on the mainland near the lagoon, and some glaucous gulls land along mainland and island beaches. After river water overflows onto the lagoon ice in early June, a few loons and some waterfowl land on the overflow water. Thus there is the potential for some spring migrants to be affected by oilspills in and near lagoons. In this section we summarize our observations of waterbirds landing in or near the lagoon during spring migration.

Loons migrate eastward through Simpson Lagoon in early and mid June. Previous studies near Prudhoe Bay (Bergman et al. 1977; Schamel 1978) have indicated that during June loons concentrate in early-melting areas off the deltas of the Sagavanirktok and Kuparuk Rivers; Schamel recorded a peak of 3.9 loons/km^2 near Egg Island on 16 June 197[illegible]. In the Simpson Lagoon area, 111 loons of all four species were seen primarily in shore-lead habitat during four aerial surveys of the lagoon area in June. Two yellow-billed loons were seen swimming and even diving in runoff waters on top of the lagoon ice off Oliktok Point on 8 June 1977, and single unidentified loons were seen on the runoff water in that area on each of 10, 11 and 12 June 1977. Numbers of loons using Simpson Lagoon in spring were apparently lower than numbers off river mouths to the east.

White-fronted geese were present on the mainland tundra and ponds during spring migration (e.g., Table 5), but rarely flew over the lagoon; none were seen to land on the lagoon ice or runoff water.

Some brant landed at ponds on the mainland near Oliktok Point, and in addition some of those flying along the lagoon on 10 and 12 June 1977 landed in the runoff water present on top of the lagoon ice. A total of 68 of the 586 migrating brant recorded from Oliktok Point in the 8-15 June 1977 period were seen to land at least briefly in the river runoff. These 68

Table 5. Densities of common waterbird species recorded on aerial transects along and near Simpson Lagoon during spring 1977-79.*

Species	Date	Density (birds/km²) on Transect 1 Beaufort Sea	2 S shore islands	3 Mid-lagoon	4 Mainland shore	5 Mainland
All Loons	1977 June 5	0	0	0	0	0
	1977 June 20	0	1.2	0	0	0.2
	1978 June 23	0	0.6	0	2.2	0.8
	1979 June 22	0	1.1	0	0	0.7
White-fronted Goose	1977 June 5	0	0	0	0	1.1
	1977 June 20	0	0	0	0	1.2
	1978 June 23	0	0	0	0	2.9
	1979 June 22	0	0	0	0	5.1
Pintail	1977 June 5	0	0	0	0	0.4
	1977 June 20	0	0	0	0	3.5
	1978 June 23	0	0	0	0	0.3
	1979 June 22	0	0	0	0	0
Oldsquaw	1977 June 5	0	0	0	0.2	2.6
	1977 June 20	0	1.6	0	0.9	3.2
	1978 June 23	0	1.3	0	0.2	1.4
	1979 June 22	0	2.5	0	0.2	0.6
All Eiders	1977 June 5	0	0	0	0	0
	1977 June 20	0	0.4	0	0.1	2.7
	1978 June 23	0	0.2	0	0	1.1
	1979 June 22	0	0.6	0	0	0.6
Glaucous Gull	1977 June 5	0	1.4	0.1	0.1	0.2
	1977 June 20	0	0.1	0	0.2	0.2
	1978 June 23	0.1	2.3	0	0.1	0
	1979 June 22	0	0.4	0	0.1	0
Arctic Tern	1977 June 5	0	0	0	0	0
	1977 June 20	0	0.7	0	0	0
	1978 June 23	0	0.2	0	0	0
	1979 June 22	0	0	0	0	0

*See Fig. 1 for transect locations.

birds included flocks of 23, 18 and 15 individuals seen on 12 June. In addition a total of 68 additional unidentified waterfowl, including a flock of 45, were seen sitting on the runoff water in mid-lagoon on 12-13 June. Most of these were probably brant. Because only a short stretch of one lagoon was in view, these results suggest that a high proportion of the brant migrating during the period after river water flows onto the landfast ice may land somewhere in the series of lagoons along the northern coast of Alaska. However, no brant were recorded during aerial surveys in June.

Dabbling ducks, including mainly pintails but a few individuals of other species (Table 2), were present on meltwater ponds on the mainland in early to mid-June. During watches at Oliktok in spring 1977 only five pintails and three green-winged teal were seen to land (very briefly in each case) on the runoff water in the lagoon.

Oldsquaws began to appear on meltwater ponds on the mainland in early June, and were also seen in small numbers on shoreleads along the shores of the barrier islands by 20-23 June (Table 5). Only a few migrants were seen landing in the runoff water on the lagoon ice off Oliktok (total of 11 birds, all on 7-10 June 1977); an additional flock of nine were sitting on the water on 10 June. Thus there was no significant build-up of oldsquaws in the lagoon prior to occupation of mainland nesting habitat.

Common and king eiders congregate on runoff water and newly-formed leads off river mouths near Prudhoe Bay in June (Bergman et al. 1977; Schamel 1978), but we saw little evidence of this phenomenon in Simpson Lagoon. During aerial surveys of the Simpson Lagoon area in spring, low densities (0.2-0.6 birds/km^2) of eiders were seen on the shoreleads along the barrier islands and somewhat higher densities were seen on ponds and lakes on the mainland tundra (0.6-2.7 birds/km^2). During migration watches from Oliktok Point conducted up to 15 June in 1977, totals of only five common, 26 king, two spectacled and 10 unidentified eiders were seen landing on, sitting on, or taking off from runoff water on the lagoon ice (10-13 June).

No jaegers, Sabine's gulls or arctic terns were seen to land on runoff water on the lagoon ice. All 10 arctic terns seen during the survey of transect 2 in spring 1977 and 1978 were flying over shoreleads south of Spy and Leavitt islands (Table 5).

Glaucous gulls were commonly seen along island and mainland shorelines in spring (e.g., Table 5). However, during watches from Oliktok in spring 1977 we saw glaucous gulls on the runoff water only three times (total of six birds).

Flight Behavior. The visual observations of spring migration in the Simpson Lagoon area in 1977-78 provide information about the heights and flock sizes of the migrants. The radar data from 1977 provide information about hourly timing.

Almost all of the birds seen migrating over the Simpson Lagoon area during the spring in 1977-78 were at estimated altitudes below 100 m (Fig. 13). Loons, brant, oldsquaws and especially eiders often flew very close to the ice (<2 m ASL). The proportion of brant estimated to be above 10 m ASL (40%) was much larger than the corresponding proportion along the Yukon coast in 1975 (5%). A considerable number of jaegers and glaucous gulls also flew very low, but these species often flew as high as 50 to 100 m ASL. Pintails and white-fronted geese rarely flew very low over the ice or tundra; most of those seen were 5 to 50 m ASL.

Flock sizes of birds seen migrating through Simpson Lagoon during the springs of 1977-78 ranged up to 150; only brant, oldsquaws and common eiders were ever seen in flocks larger than 40 (Fig. 14). Migrating jaegers, glaucous gulls and pintails were occasionally seen in flocks as large as 30 or 40, but migrating loons, white-fronted geese and arctic terns were never seen in flocks larger than 10.

Visual observations of numbers migrating over Simpson Lagoon in relation to time of day have not been analyzed yet, but the Oliktok radar showed very similar median densities of migration at all times of the day (Fig. 15). All species are grouped together in the radar data, but there are two *a priori* reasons for suspecting that, for most species, there would be little diel variation in the rate of spring migration: (1) There is continuous daylight in northern Alaska during spring migration; (2) Many birds are apparently engaged in long-distance non-stop migrations when they pass through Simpson Lagoon in spring; during such migrations any diel pattern in take-off times from distant take-off areas tends to be obscured by variations in flight speeds and distances traveled.

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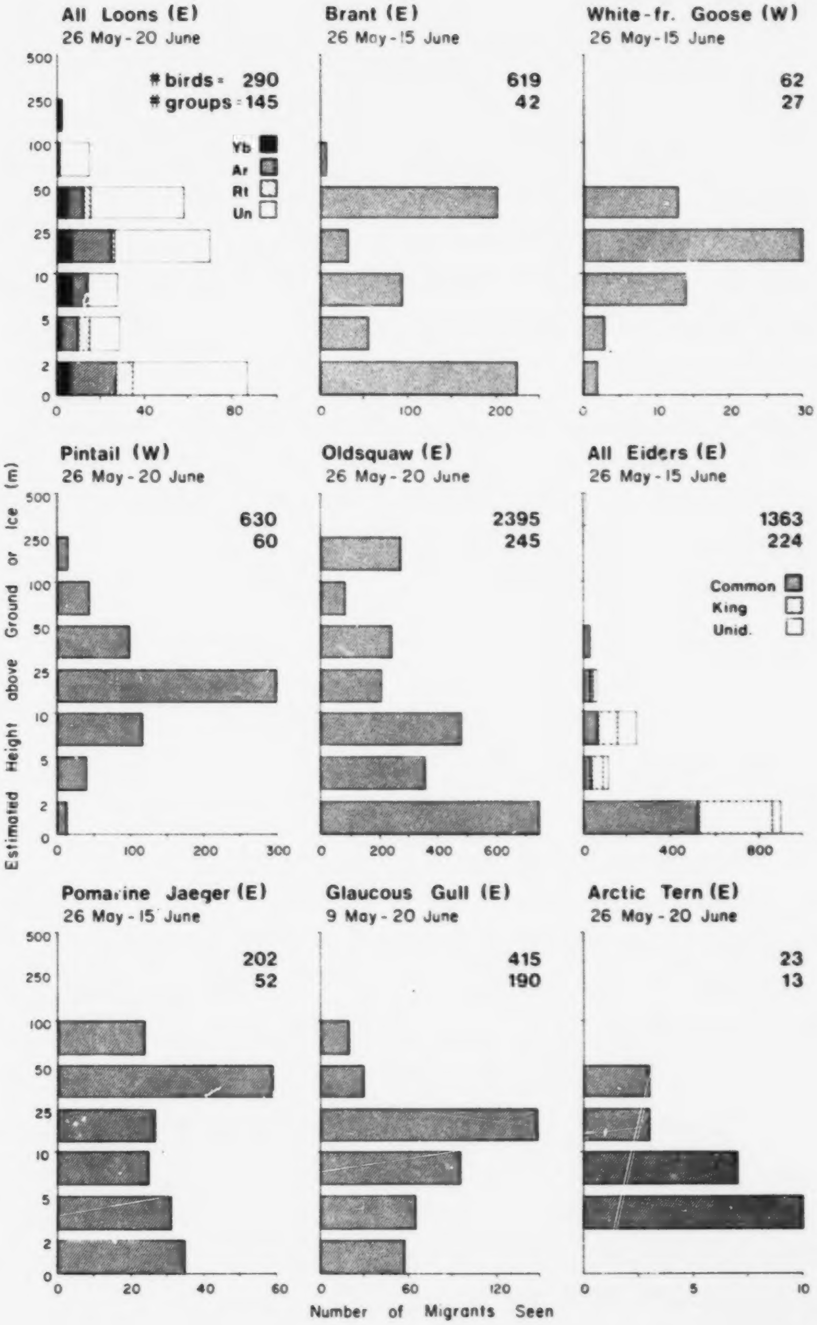

Figure 13. Estimated heights (m) of spring migrants in the Simpson Lagoon area, 1977-78. Observations from Oliktok, Pingok Island and Milne Point are pooled. Only birds that flew continuously and eastward (or, in the case of white-fronted geese and pintails, westward) during systematic migration watches are considered. Birds >3 km offshore or >1 km inland excluded. Sightings during periods with visibility <3 km excluded.

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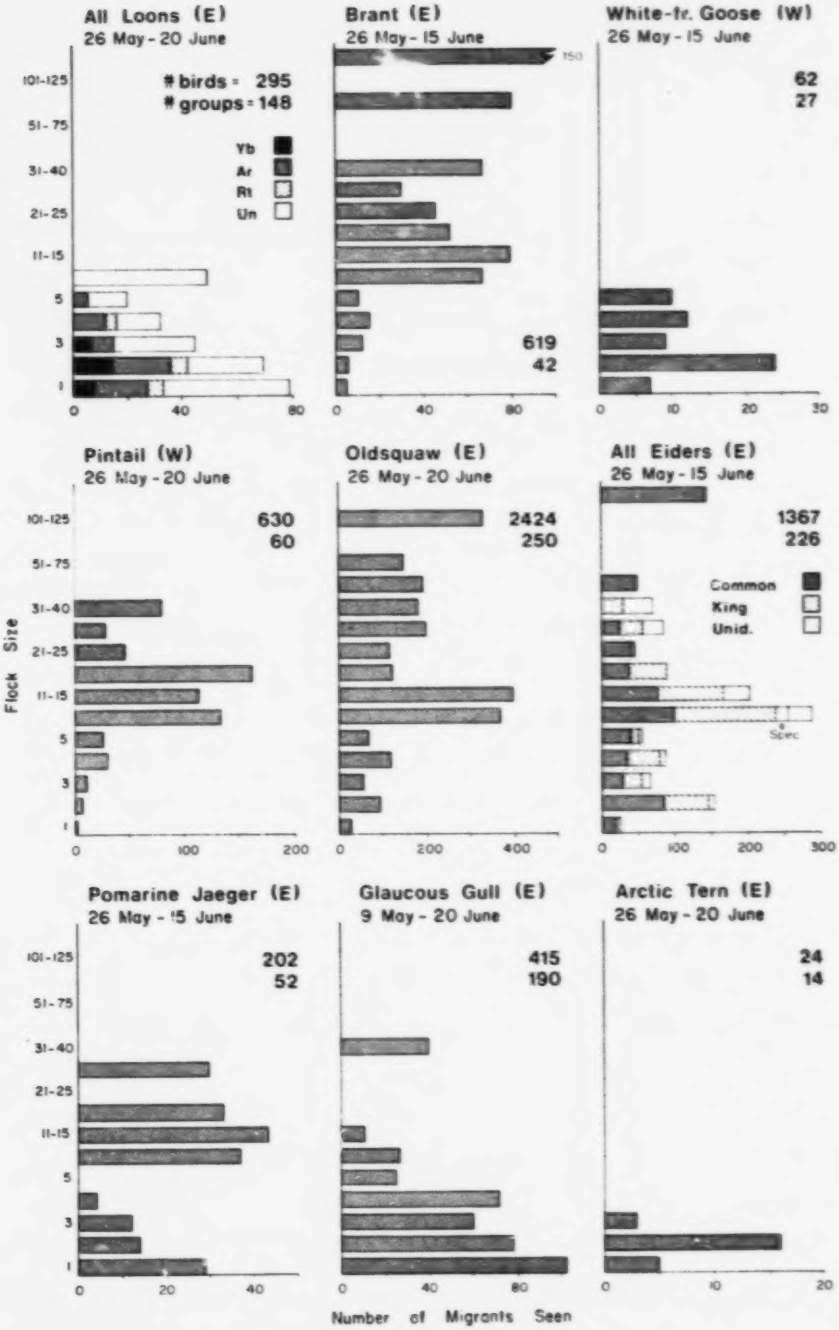

Figure 14. Flock sizes of spring migrants in the Simpson Lagoon area, 1977-78. The total numbers of migrants seen in flocks of various sizes are shown. Mixed-species flocks are each tabulated as 2 or more flocks (e.g., a flock of 5 king and 3 common eiders is tabulated as 2 flocks of sizes of 5 and 3). Criteria for inclusion same as in previous diagram.

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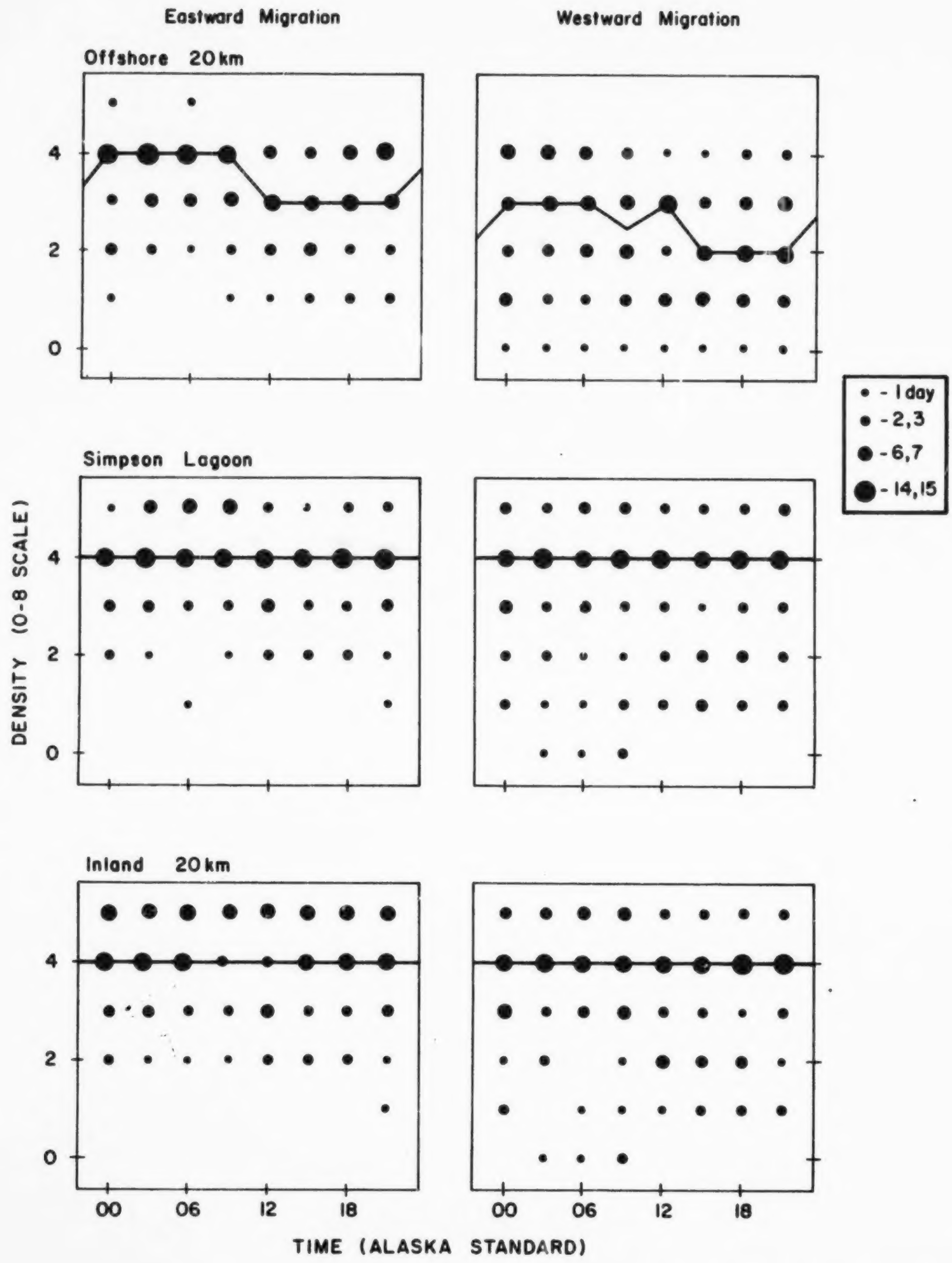

Figure 15. Density of eastward (left) and westward (right) migration detected by Oliktok radar in relation to time of day, 25 May - 20 June 1977. The line shows the median density at each time of day. Each column of data points shows the distribution of densities (0 to 8 ordinal scale) recorded at one time of day, with areas proportional to the number of days represented.

Molt Migration

The most conspicuous movements of birds through the Simpson Lagoon area during late June and July of 1977 and 1978 were westward movements of male seaducks--oldsquaws, eiders and scoters (Table 6). These birds were presumably migrating to molting areas in or west of the study area. Large numbers of eiders (mainly king eiders) fly west around Point Barrow in mid and late July (Thompson and Person 1963; Johnson 1971). Relatively few oldsquaws or eiders fly west immediately along the Yukon coast during the molt migration, but there is a significant westward migration of scoters along the Yukon coast toward Alaska (Table 6).

Seasonal Timing. During both 1977 and 1978 the westward molt migration of male oldsquaws was first noted on 26 June. This was the only day with systematic watches in late June of 1977, but molt migration had not been obvious during casual observations on previous days. In 1978 there were daily watches in late June. Peak numbers of oldsquaws moved west from 2 to 4 July in 1977 and from 3 to 7 July in 1978 (Fig. 16, Table 7). Thereafter, westward movement continued sporadically until late July. In both 1977 and 1978 there was a second, smaller peak of westward movement just before the molt migration ceased (24-25 July 1977 and 23-25 July 1978).

The westward molt migration of male common and king eiders was first noted on 2 July 1977 and 24 June 1978 and continued until approximately 31 July 1977 and 12 August 1978. During the latter parts of these periods the only data obtained were from casual observations. Most westward movement by eiders occurred after the lagoon ice had broken up and had been flushed westward, out of the study area (Simpson Lagoon began breaking up on 9 July 1977 and 5 July 1978 and was virtually ice-free within one or two days). Peak numbers of eiders were seen moving west from 21 to 25 July 1977 and from 3 to 11 and 27 to 30 July 1978 (Fig. 16, Table 7). A few female and/or immature male eiders accompanied the westbound adult males.

During 1978, a westward molt migration by scoters, primarily male surf scoters and to a lesser extent male white-winged scoters, coincided with that of oldsquaws. Three white-winged scoters flying NNE were seen on 28 June,

Table 6. Total numbers of ducks seen flying east and west near the Beaufort Sea coast during systematic watches in the molt migration period.[a]

	Yukon Coast[b]				Simpson Lagoon Area			
	1972		1975		Pingok Isl. 1977		Milne Pt. 1978	
Species	West	East	West	East	West	East	West	East
Pintail	13	0	47	12	11	0	15	0
Scaup	19	113	0	0	0	0	18	84
Oldsquaw	484	295	157	183	1659	88	8379	643
Eiders	96	42	3	8	1471	8	725	57
Common	-[c]	-	3	8	289	6	349	31
King	-	-	0	0	977	2	65	21
Spectacled	0	0	0	0	6	0	6	0
Unidentified	-	-	0	0	199	0	305	5
Scoters	953	263	869[d]	37[d]	0	0	893	23
White-winged	-[c]	-	71	3	0	0	19	0
Surf	-	-	423	25	0	0	720	22
Unidentified	-	-	375	9	0	0	154	1
Red-breasted Merganser	49	26	18	30	0	0	13	17
Dates with data	10 July- 31 July		26 June- 9 July		26 June- 25 July		26 June- 28 July	
Hours of observation	72.4		123.4		33.5		90.3	

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[a] Includes migrants seen at all distances from shore during systematic watches. Watches when the visibility was less than 3 km were excluded in 1975-78.

[b] Yukon data for 1975 were observations from Komakuk and Clarence Lagoon (Johnson et al. 1975; Richardson et al. 1975); some birds were probably counted twice, once at each site. Yukon data for 1972 were observations from the base of Nunaluk Spit, 14 km east of Komakuk (Gollop and Davis 1974).

[c] Data for individual species of eiders and scoters not available for 1972.

[d] In addition to these totals, during 113.1 h of observations in the 16-25 June 1975 period a total of 571 scoters (4 white-winged, 112 surf, 455 unidentified) were seen flying west and 73 scoters (67 surf, 4 black, 2 unidentified) were seen flying east. No scoters were seen before 26 June in 1978.

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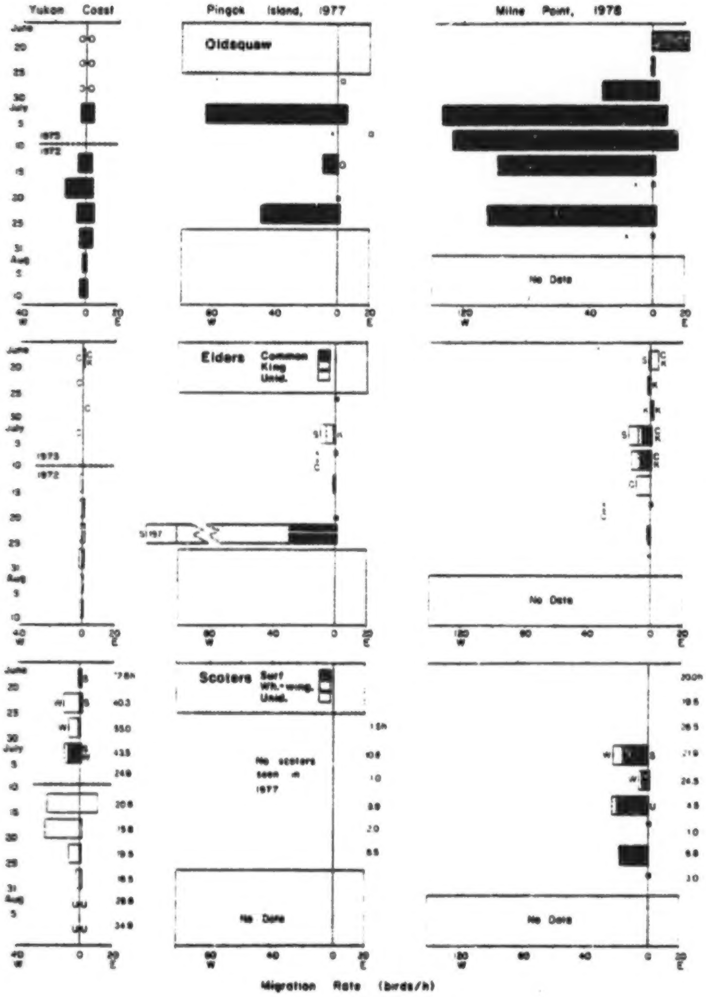

Figure 16. Rates of westward (left of baseline) and eastward (right of baseline) migration of oldsquaws, eiders and scoters by 5-day periods during the molt migration period. Includes birds at all distances from shore. Letters mean 'seen but rate too low to be plotted'. For periods in which there were observations on only 1 or 2 days, rates are shown by 'x' (westward) and '□' (eastward). Stippled areas indicate dates with no observations. The number of hours of observations in each 5-day period is given in the 'scoter' section (periods with visibility < 3 km omitted in 1975-78). Yukon data are those of Johnson et al. (1975) for 1975 and Gollop and Davis (1974) for 1972.

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Table 7. Numbers of oldsquaws, eiders, scoters and unidentified diving ducks sighted flying in various directions through Simpson Lagoon during the mid-summer molt migration in 1977 and 1978. Includes casual observations as well as sightings during systematic migration watches.

	1977								1978							
	June	July						Total	June	July						Total
	26-30	1-5	6-10	11-15	16-20	21-25	26-31		26-30	1-5	6-10	11-15	16-20	21-25	26-31	
Oldsquaws																
Eastbound	3	61	20	2	0	6	0	92	97	209	363	5	0	11	0	685
Westbound	240	1373	4	571	135	451	0	2774	1064	3122	3127	447	11	1133	168	9072
Other*	140	264	126	1722†	131	361	0	2744	2221	2472†	32505†	67	6709	628	66	44668
Eiders																
Eastbound																
Common Eider	0	0	0	0	0	6	0	6	23	8	4	0	0	0	0	35
King Eider	0	2	0	0	0	6	0	8	9	9	3	0	0	0	0	21
Unidentified Eiders	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	5
Westbound																
Common Eider	0	16	12	12	618	1002	250	1910	6	152	164	3	40	54	386	805
King Eider	0	51	0	86	115	1679	0	1931	14	33	18	0	0	0	0	65
Unidentified Eiders	1	53	0	5	7	166	0	232	3	226	124	37	15	26	42	473
Other*																
Common Eider	4	1	0	5	0	20	0	30	0	38	30	0	0	0	0	68
King Eider	0	2	0	0	0	2	0	4	37	52	30	4	0	5	0	128
Unidentified Eiders	0	7	2	12	41	61	0	123	4	8	19	2	0	41	71	145
Scoters																
Eastbound																
Surf Scoter	0	0	0	0	0	0	0	0	0	3	19	0	0	0	0	22
White-winged Scoter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unidentified Scoters	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Westbound																
Surf Scoter	0	0	0	0	0	0	0	0	0	384	110	251	0	161	0	906
White-winged Scoter	0	0	0	0	0	0	0	0	0	3	1	15	0	0	0	19
Unidentified Scoters	0	0	0	0	0	0	0	0	0	121	33	0	0	0	0	154
Other*																
Surf Scoter	0	0	0	0	0	0	0	0	0	13	41	1	0	0	0	55
White-winged Scoter	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3
Unidentified Scoters	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unidentified Diving Ducks																
Eastbound	0	0	0	0	0	0	0	0	0	142	27	0	0	0	0	169
Westbound	0	0	0	0	0	600	0	600	8	637	164	0	43	55	20	927
Other*	0	0	0	12	45	20	0	77	1	64	43	6	2	4	49	169

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*'Other' includes sitting birds, birds flying north or south and flying birds that were considered not to be migrants or whose migrant status was unknow

†The ice on the surface of Simpson Lagoon began to break up on 9 July 1977 and on 5 July 1978 and had departed the study area by 11 July 1977 and by 6 July 1978. For a short period after those dates, the number of locally flying oldsquaws in the study area increased dramatically.

but the first westbound surf and white-winged scoters were recorded on 1 July. The peak of westward movement by scoters occurred during the 4 through 12 July period. A second peak of movement by surf scoters occurred on 24 and 25 July 1978 (Fig. 16). No migrating scoters were seen during the corresponding period of 1977, and only one scoter was seen during aerial surveys of Simpson Lagoon in July 1977. Almost all scoters seen during the 1978 molt migration were males; of those whose sex was recorded, only four were females (surf scoters on 7 July 1978).

In the northern Yukon, surf scoters began migrating west on 18 June in 1975, and white-winged scoters began by 26 June. Many scoters flew west along the Yukon coast in mid July of 1972, and a few flew west as late as 30 July in 1972 (Fig. 16). Almost all scoters seen during the 1975 molt migration were males; the only females identified were six surf scoters seen on 3-5 July.

Flight Paths and Behavior. Radar was not used during the molt migration periods of 1977 or 1978, so we have only local observations of migration routes. During 1977, the only migration watch station used in summer was located on Pingok Island; consequently movements were detectable along the lagoon shoreleads and over the fractured lagoon ice, as well as over the frozen Beaufort Sea seaward of the barrier islands. The migration watch station during 1978 was located on the mainland shoreline at Milne Point and many movements by migrating birds seaward of the barrier islands were undoubtedly undetected.

Most oldsquaws seen flying west before the ice left Simpson Lagoon were flying along shoreleads near the mainland or island shores, or over the lagoon ice. After the ice cleared from the lagoon, most of those seen from both Pingok Island (1977) and the mainland (1978) were flying along the lagoon. Only a few of those seen in 1978 flew west over the mainland south of Milne Point. Migrating oldsquaw flew in flocks of widely varying sizes, including one flock estimated to contain 1000 birds. Almost half (46%) of those seen flew at estimated altitudes of only 0 to 2 m above the water or ice; the others flew at a variety of heights, with many up to at least 250 m (Fig. 17).

Before breakup, most eiders seen flying west were moving along shoreleads and over the lagoon ice. After breakup of the lagoon ice, most of those seen were over the lagoon. However, there was also westward movement

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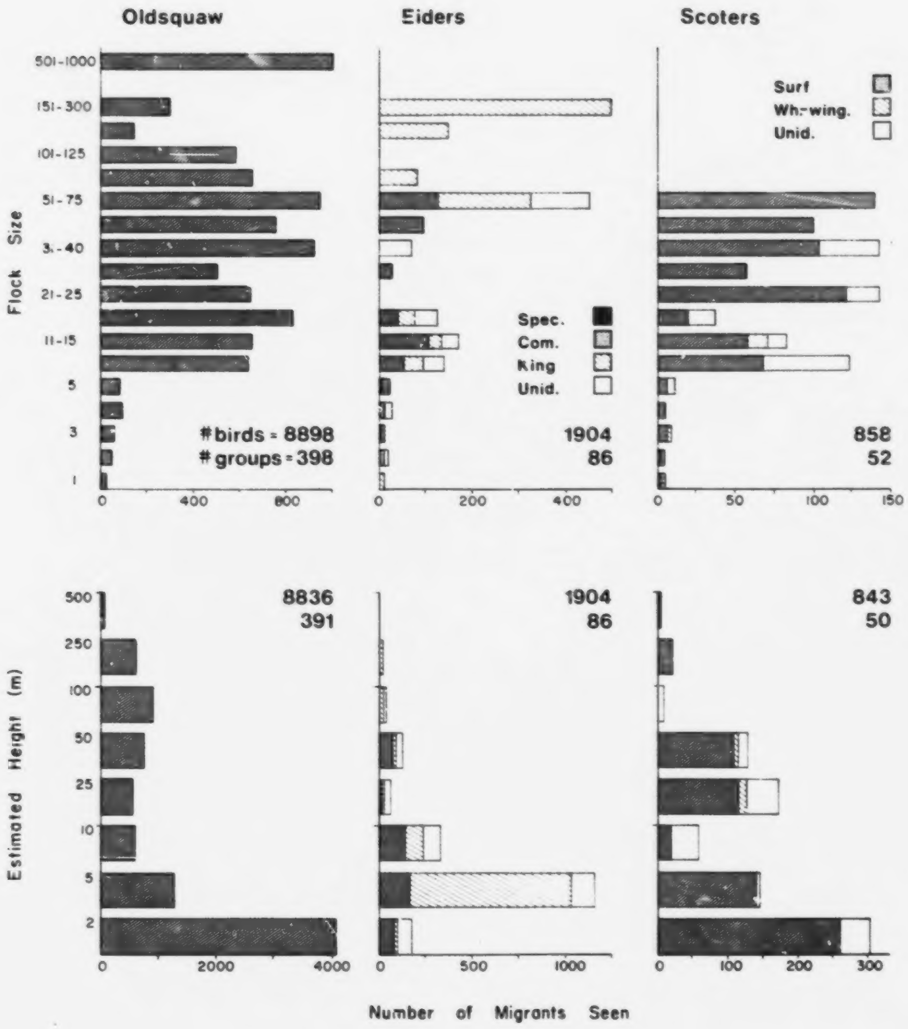

Figure 17. Flock sizes and estimated heights (m) of ducks migrating west over the Simpson Lagoon area during the molt migration period, 25 June - 31 July 1977-78. Criteria for inclusion same as in Figures 13 and 14.

over the Beaufort Sea north of the barrier islands during late July 1977, following breakup of the sea ice. Eiders flew in flocks of a wide variety of sizes (Fig. 17). Most flew at estimated altitudes below 10 m.

The great majority of the westbound scoters seen from Milne Point were flying over shoreleads, ice or open water in Simpson Lagoon. However, some were flying over the mainland south of Milne Point. Similarly, in the Yukon in 1975 most westbound scoters seen were over the sea, but a minority were flying west overland. Some of those seen from Milne Point were over the central part of the lagoon, so it is doubtful that the paucity of scoters in 1977 was due solely to the fact that the observation site in 1977 was on Pingok Island. Flocks of migrating scoters ranged in size up to 75 birds at Simpson Lagoon in 1978 (Fig. 17) and 175 birds in the Yukon in 1975. The largest flocks in both areas consisted of surf scoters.

Numbers. We cannot make reliable estimates of total numbers of seaducks migrating through Simpson Lagoon during the molt migration period, partly because watches were conducted on only some of the days, partly because watches were most frequent on days with much molt migration, and partly because only one watch site was used each year. Table 7 presents the total numbers actually seen to migrate west through the Simpson Lagoon area during the 26 June-31 July period: oldsquaw--2774 in 1977 and 9072 in 1978; eiders--4073 and 1343; scoters--0 and 1079. These totals include casual observations, but nonetheless represent only a fraction of the total migration through the area.

More realistic minimum estimates are possible for 1978 because during the 26 June-10 July 1978 period there were daily systematic watches totalling 72.9 h of observation. If the observed migration rates for these three 5-day periods (Fig. 16) are assumed to apply to all hours in those periods, and the actual numbers seen during the 11-31 July period are added, the following minimum estimates are obtained:

	Estimate, 26 June-10 July	No. Seen, 11-31 July	Minimum Estimate of Total
Oldsquaw	32,210	1,743	33,953
Common Eider	1,416	483	1,899
King Eider	228	0	228

	Estimate, 26 June-10 July	No. Seen, 11-31 July	Minimum Estimate of Total
Spectacled Eider	32	0	32
Unident. Eiders	1,323	120	1,443
All Eiders	2,999	603	3,6[illegible]
All Scoters	3,239	426	3,665

These figures are net values (i.e., westward minus eastward movement), and are undoubtedly underestimates because the values for 11-31 July are incomplete and because observers at Milne Point could not detect all ducks migrating over the northern side of the lagoon ([illegible]-5 km away).

Numbers of oldsquaws and eiders migrating west along the Yukon coast during the molt migration period were much lower than numbers migrating through Simpson Lagoon (Fig. 16). Rates of scoter migration along the Yukon coast in 1972/75 and through Simpson Lagoon in [illegible] were more similar (Fig. 16). If the net rates of westward migration along the Yukon coast shown in Fig. 16 are applied to all hours in the 16 June-31 July period, an estimated 8129 scoters flew west within sight of coastal observers toward Alaska. The 8129 estimate is tentative because it is based on incomplete but complementary results from two years; it could be biased if migration timing were different in the two years.

Utilization of Study Area. Observations during migration watches and other activities in 1977 and 1978 indicated that during the molt migration, oldsquaws and a few scoters made moderate use of water-filled cracks in the lagoon ice and of the shoreleads around the perimeter of the barrier islands and along the mainland shoreline. Eiders made only light use of lagoon and nearshore marine habitats during molt migration. We do not know what proportion of the seaducks that flew west along the lagoon landed somewhere in the lagoon, but aerial surveys provided information about densities and numbers of ducks in the lagoon area on various dates.

Oldsquaws made only moderate use of the lagoon during the period of peak westward molt migration in early July, but large numbers of molting oldsquaw concentrated in the lagoon later in the month (Table 8). Only shoreleads were present throughout the period of peak movement in 1977 (2-4 July), but general breakup of the lagoon ice occurred during the peak

Table 8. Densities of oldsquaws, eiders and scoters recorded on aerial transects along and near Simpson Lagoon during the molt migration period, 1977-79.*

Date	Density (birds/km²) on Transect				
	1 Beaufort Sea	2 S shore islands	3 Mid-lagoon	4 Mainland shore	5 Mainland
Oldsquaw					
1977 Jul 5	2.2	26.2	2.9	21.6	1.9
" " 28/29	0.1	401.7	501.1	516.4	1.2
1978 Jul 5	0.1	160.4	5.4	2.2	1.4
" " 15	2.5	1344.8	39.0	70.8	0.2
" " 25	17.7	284.7	73.0	19.1	0
" Aug 5/6	0.2	324.7	62.5	6.4	0
1979 Jul 28/29	4.2	520.5	132.6	31.2	8.6
Eiders[a]					
1977 Jul 5	0	0.3	0	1.2	1.8
	-	(0.1c)	-	-	-
" " 28/29	1.5	1.2	0	0.9	0.8
	(1.0c)	(0.2c)	-	-	-
1978 Jul 5	0	0.3	0	0.6	0
	-	-	-	(0.1k)	-
" " 15	0	0.4	0	0	0.7
	-	(0.1c)	-	-	-
" " 25	1.1	1.5	0	0.1	0.4
	(0.7c)	-	-	-	(0.4k)
" Aug 5/6	0	0	0	0	1.2
	-	-	-	-	-
1979 Jul 28/29	0.4	1.6	0	0.9	0
	-	-	-	-	-
Surf Scoter[b]					
1977 Jul 5	0	0.1	0	0	0
1978 Jul 5	0	2.7	0	0	0
" " 15	0	1.0	0.7	0	0
" " 25	0	50.4	0.7	0	0

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[a] When eiders were identified to species, the density of identified eiders is given in parentheses below the total density.

[b] No scoters seen during the other 3 surveys listed under eiders. All scoters seen during aerial surveys in July 1978 were surf scoters. Those seen on 5 July 1977 were unidentified scoters.

period in 1978 (3-7 July). In both years the nearshore Beaufort Sea north of the barrier islands remained frozen (except for shoreleads) throughout the period of peak westward molt migration. The estimated numbers of oldsquaws in Simpson Lagoon on 5 July in 1977 and 1978 were only about 1000 and 2500, respectively (see later section on 'MOLTING' for details). By 15 July 1978 about 29,000 were estimated to be present, and in late July the estimates for 1977-79 were about 51,000 (28/29 July 1977), 13,000 (25 July 1978) and 23,000 (28 July 1979). These results suggest that during the peak of molt migration in early July most oldsquaws that pass over Simpson Lagoon do so without stopping for any significant period (if at all). Later in July, after the lagoon ice breaks up and leaves the lagoons, large numbers of molting oldsquaw concentrate in the lagoon.

Few eiders were present in or near Simpson Lagoon during the molt migration period (Table 8). During aerial surveys in July, only small numbers of eiders were seen near the barrier islands (where common eiders nest) and the mainland shore, and none were seen in mid lagoon. In late July of each year, during breakup of ice in the nearshore Beaufort Sea, a few eiders (most if not all common eiders) were seen along the transect several kilometers seaward of the barrier islands.

During most aerial surveys of Simpson Lagoon scoters were seen in only small numbers if at all (Table 8). However, on 25 July 1978, around the end of the molt migration period of scoters, about 750 surf scoters (mostly males) were seen near the south shore of Pingok Island. In addition, scoters were seen during our aerial surveys of eastern Harrison Bay on 5 and 15 July 1978 and in late summer of 1978. In 1971, Hall (1975) observed 200-300 surf scoters in Harrison Bay during August, and Gavin (1976) indicates that scoters occur in the Simpson Lagoon area in 'fall' (dates not stated). Thus, it appears that male scoters not only migrate west through Simpson Lagoon, but that a few hundred remain in the area to molt.

Small number of greater scaup were seen flying through the Simpson Lagoon area, mainly eastward, during the molt migration period (Table 6). They were never recorded during aerial surveys of the lagoon in July, but small numbers were seen in Harrison Bay just west of Simpson Lagoon ($2.7/km^2$ on transect 6 on 5 July 1978; $2.3/km^2$ on transect 7 on 15 July 1978).

In summary, during late June and July male oldsquaws migrated west through Simpson Lagoon in large numbers (over 30,000), and male eiders and scoters did so in smaller numbers. In addition, large numbers of oldsquaw and very small numbers of surf scoters concentrated in Simpson Lagoon to molt. Small numbers of scaup may molt in Harrison Bay.

Fall Migration

Fall migration of waterbirds through and from the coastal Beaufort Sea area begins in mid-August and continues not only during September (when systematic observations have been made) but also during October and even early November (Gabrielson and Lincoln 1959; Flock 1973). Our systematic observations ended around 22 September, and earlier migration studies at Point Barrow (Thompson and Person 1963; Johnson 1971; Timson 1976) and in the northern Yukon (Gollop and Davis 1974; Schweinsburg 1974a) ended earlier in September. Waterbirds still present in the Simpson Lagoon area in late September include many oldsquaws and glaucous gulls as well as some loons, eiders and scoters (Table 9). Thus, systematic data are available for only the earlier portion of the fall migration season.

A further limitation is that our systematic watches in 1977 were from only one site, Pingok Island, and totalled only 38.6 h on 27 days (watches with visibility <3 km excluded) in the 21 August-22 September period. In 1978, incidental observations of fall migration were recorded daily until 5 September, but systematic migration watches were not possible.

Because data concerning fall migration in the Simpson Lagoon area are limited, we have summarized relevant data from other parts of the Beaufort Sea, as well as our own results, in the following sections.

Loons. Westward migration of loons through the Simpson Lagoon area began in late August (Table 10). In 1977 it apparently peaked in the 26-31 August and 1-5 September periods (4.4 and 5.0 loons/h, respectively). A few loons were still present on 22-23 September in 1977-79 (Table 9). Previous studies at Point Barrow indicate that very few loons pass that site in late August; peak loon migration there is in the first half of September (Seale 1898; Timson 1976; Divoky 1978a:480) or perhaps even later.

Table 9. Densities of common waterbird species recorded on aerial transects along and near Simpson Lagoon during August and September 1977-79.^{a}

Species	Date	Density (birds/km^2) on Transect						
		1 Beaufort Sea	2 S shore islands	3 Mid-lagoon	4 Mainland shore	5 Mainland	6 Harrison Bay SE	7 Harrison Bay S
All Loons	1977 Aug 15	-^{b}	0.1	-	0.4	1.3	-	-
	" " 30	0.2	0.3	0	0.1	1.8	-	-
	" Sep 22	0.1	0	0.2	0	0	-	-
	1978 Aug 5/6	0	0	0	0	0	0	0
	" " 15	0	0	0	0	0	0	0
	" " 25	0	0.1	0	0.2	0.1	0	-
	" Sep 5/6	0.1	0	0	0.4	0.4	0	0.2
	" " 15	0.1	0.1	0.1	0.2	0	0	0
	" " 23	0	0	0.2	0	0	0	0
	1979 Aug 31	0	0.1	0	0.3	0.6	0.2	0
	" Sep 23	0	0	0	0	0	0.2	0
White-fronted Goose	1977 Aug 15	0	0	0	0	2.9	-	-
	" " 30	0	0	0	0	2.4	-	-
	" Sep 22	0	0	0	0	0	-	-
	1978 Aug 5/6	0	0	0	0	0	0	0
	" " 15	0	0	0	0	0.6	0	0
	" " 25	0	0	0	0	4.4	2.7	-
	" Sep 5/6	0	0	0	0	1.8	0	-
	" " 15	0	0	0	0	0	0	0
	" " 23	0	0	0	0	0	0	0
	1979 Aug 31	0	0	2.4	0	3.1	0	0
	" Sep 23	0	0	0	0	0	0	0
Oldsquaw	1977 Aug 15	-	811.3	-	161.9	5.8	-	-
	" " 30	3.3	73.1	184.6	68.0	0	-	-
	" Sep 22	3.4	21.6	928.1	220.0	0	-	-
	1978 Aug 5/6	0.2	324.7	62.5	6.4	0	215.1	20.9
	" " 15	0	994.2	7.3	0	0	679.6	106.7
	" " 25	50.2	337.4	33.3	0.8	2.0	287.6	-
	" Sep 5/6	20.2	150.2	12.3	0.1	0.1	246.4	30.1
	" " 15	193.3	47.0	29.6	7.1	0	6.9	11.4
	" " 23	1.6	9.9	231.8	138.5	0	3.1	0
	1979 Aug 31	24.7	78.9	330.3	0	0	239.0	23.8
	" Sep 23	15.8	231.6	3.4	113.7	0	1.6	30.0

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Species	Date	Density (birds/km^2) on Transect 1 Beaufort Sea	2 S shore islands	3 Mid-lagoon	4 Mainland shore	5 Mainland	6 Harrison Bay SE	7 Harrison Bay S
All Eiders	1977 Aug 15	-	1.9	-	0.1	0	-	-
	" " 30	0	0.2	0	0.1	0	-	-
	" Sep 22	0.4	2.9	0	0	0	-	-
	1978 Aug 5/6	0	0	0	0	1.2	0	0
	" " 15	0	1.0	0	0	0.1	0	0
	" " 25	0	0	0	0	0	0	-
	" Sep 5/6	0	0.9	0	0	0	4.9	0
	" " 15	0.8	2.2	0	0	0	2.5	0
	" " 23	0	2.2	0.1	0.1	0	4.7	0.9
	1979 Aug 31	0	2.1	0	0	0	1.1	0.2
	" Sep 23	0	4.8	0	0	0	1.8	0
All Scoters	1977 Aug 15	-	0	-	0	0	-	-
	" " 30	0	0	0	0	0	-	-
	" Sep 22	0	0.1^c	1.8	0	0	-	-
	1978 Aug 5/6	0	0	0	0	0	0	0
	" " 15	0	0	0	0	0	0	1.9
	" " 25	0	0	0.4	0	0	8.5	-
	" Sep 5/6	0	0	0	0	0	0	0
	" " 15	0	0	0	0	0	9.2	0.8
	" " 23	0	0	0.6	0	0	0	0
	1979 Aug 31	0	0	0	0	0	0	0
	" Sep 23	0	0	0	0	0	0	0
Glaucous Gull	1977 Aug 15	-	7.6	-	1.1	0.1	-	-
	" " 30	0.1	25.5	0	1.4	0.2	-	-
	" Sep 22	0	193.0	0	18.6	0	-	-
	1978 Aug 5/6	0	0.1	0	0.2	0	1.3	1.2
	" " 15	0	0.9	0	0.4	0.1	0.5	-
	" " 25	0	0	0.1	0.2	0.1	0	0
	" Sep 5/6	0	4.5	0	0.7	0.1	6.9	0
	" " 15	0.1	6.3	0	0.1	0.1	4.9	1.9
	" " 23	0	16.1	0.1	1.4	0.1	0.9	2.3
	1979 Aug 31	0.1	20.5	0	1.6	4.7	5.9	0.3
	" Sep 23	0	80.5	0	0.5	0.5	18.0	0

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Page 3...

		Density (birds/km^2) on Transect						
Species	Date	1 Beaufort Sea	2 S shore islands	3 Mid-lagoon	4 Mainland shore	5 Mainland	6 Harrison Bay SE	7 Harrison Bay S
Arctic	1977 Aug 15	-	24.0	-	0	0	-	-
Tern	" " 30	0.4	7.4	0	0	0	-	-
	" Sep 22	0	0	0	0	0	-	-
	1978 Aug 5/6	0	0.1	0	0	0	0	0
	" " 15	0	2.4	0	0	0	0	-
	" " 25	0.6	0	0	0	0	0	0
	" Sep 5/6	0	0	0	0	0	0	0
	" " 15	0	0	0	0	0	0	0
	" " 23	0	0	0	0	0	0	0
	1979 Aug 31	0	0	0	0	0	0	0
	" Sep 23	0	0	0	0	0	0	0
Transect length (km)		35.4	37.0	30.6	32.2	33.8	13.8	16.1

[a] See Fig. 1, 2 for transect locations.

[b] '-' means transect not surveyed on this date.

[c] Black scoter.

Table 10. Birds recorded during fall migration (August-September) in 1977 and 1978, Simpson Lagoon, Alaska. Most 1977 data are from watches at Pingok Island; 1978 data are from incidental observations at Milne Point and in the lagoon area.

Species	Number Seen* (1977)		Number Seen* (1978)		Period of Peak Abundance (1977)	Period of Peak Abundance (1978)	Predominant Migration Direction (1977)	Predominant Migration Direction (1978)	Peak Migration Rate (# birds per day) (1977)	Peak Migration Rate (# birds per day) (1978)
Yellow-billed Loon	2	(5)	0	(4)	1 Se	29 Au	W	-	2	-
Arctic Loon	0	(25)	0	(1)	24 Au-14 Se	5 Se	L	-	-	-
Red-throated Loon	9	(17)	0	(2)	30 Au-1 Se	5 Se	W	-	7	-
Unidentified Loons	88	(332)	39	(65)	25 Au-6 Se	9 Se	W	W	20	39
Brant	4638	(4686)	10885	(11148)	22 Au-6 Se	17-31 Au	W	W	2261	2605
White-fronted Goose	280	(288)	-	(12)	19-24 Au	-	W	L	270	-
Unidentified Geese	852	(908)	656	(696)	24-29 Au	24 Au	W	W	800	650
Pintail	11	(60)	6	(17)	24 Au	5 Se	E	E	11	6
Greater Scaup	-	(0)	8	(8)	-	21 Au	-	E	-	8
Unidentified Scaup	0	(2)	-	(0)	18 Se	-	-	-	-	-
Oldsquaw	1730	(114266)	0	(21032)	27 Au-21 Se	14-29 Au	W	L	1000	-
Common Eider	57	(57)	135	(185)	24-26 Au	12 Au	W	W	47	135
King Eider	-	(0)	-	(5)	-	-	-	-	-	-
Unidentified Eiders	600	(600)	180	(202)	23-28 Au	5-13 Au	W	W	425	90
Unidentified Mergansers	300	(300)	-	(0)	23 Se	-	W	-	300	-
Unidentified Diving Ducks	35	(110)	20	(24)	22 Au-6 Se	13 Au	W	W	20	20
Unidentified Ducks	373	(409)	700	(2184)	27-29 Au	13 Au	W	W	233	700
Peregrine Falcon	0	(1)	-	(0)	22 Au	-	-	-	-	-
American Golden Plover	0	(27)	-	(0)	22-27 Au	-	L	-	-	-
Black-bellied Plover	6	(181)	-	(0)	28-30 Au	-	W	-	4	-
Unidentified Plovers	7	(11)	-	(0)	22 Au	-	W	-	7	-
Ruddy Turnstone	0	(30)	-	(0)	22-31 Au	-	L	-	-	-
Whimbrel	0	(1)	-	(0)	17 Au	-	-	-	-	-
Pectoral Sandpiper	0	(6)	0	(6)	24 Au-2 Se	18 Au	L	L	-	-

...continued

Species	Number Seen*		Period of Peak Abundance		Predominant Migration Direction		Peak Migration Rate (# birds per day)	
	(1977)	(1978)	(1977)	(1978)	(1977)	(1978)	(1977)	(1978)
Dunlin	3 (310)	0 (39)	28 Au	17 Au	W	L	3	-
Sanderling	0 (8)	- (0)	30 Au-2 Se	-	L	-	-	-
Semipalmated Sandpiper	0 (18)	- (0)	19 Au	-	-	-	-	-
Long-billed Dowitcher	13 (78)	0 (47)	19 Au	25 Au	W	L	13	-
Unidentified Dowitchers	0 (12)	0 (9)	31 Au	29 Au	L	L	-	-
Red Phalarope	0 (27)	0 (108)	22-28 Au	12 Au	L	L	-	-
Northern Phalarope	- (0)	0 (160)	-	12 Au	-	L	-	-
Unidentified Phalaropes	28 (1143)	0 (1307)	25 Au	23 Au	W	L	28	-
Unidentified Shorebirds	29 (581)	- (0)	21-28 Au	-	W	-	6	-
Pomarine Jaeger	1 (5)	- (0)	1 Se	-	W	-	1	-
Parasitic Jaeger	0 (3)	- (0)	22 Au-1 Se	-	L	-	-	-
Long-tailed Jaeger	0 (13)	- (0)	24-31 Au	-	L	-	-	-
Unidentified Jaegers	1 (5)	- (0)	30 Au	-	W	-	1	-
Glaucous Gull	275 (1044)	- (12)	28 Au-15 Se	-	W	L	200	-
Sabine's Gull	0 (2)	0 (3)	22 Au	14 Au	-	-	-	-
Black-legged Kittiwake	0 (1)	- (0)	19 Se	-	-	-	-	-
Arctic Tern	100 (380)	20 (85)	15-28 Au	12 Au	W	W	32	20
Thick-billed Murre	- (0)	0 (1)	-	17 Au	-	L	-	-
Varied Thrush	0 (1)	- (0)	7 Se	-	-	-	-	-
Yellow Warbler	0 (1)	- (0)	5 Se	-	-	-	-	-
Snow Bunting	0 (64)	- (0)	21 Au-2 Se	-	L	-	-	-
Lapland Longspur	0 (2)	8 (16)	22-24 Au	4 Se	L	W	-	8

*Numbers inside parentheses represent the total number of birds seen during migration watches and during incidental observations (includes birds that were not actively migrating).
Numbers to the left of those in parentheses represent the number of birds seen migrating during the period of peak abundance. There were no systematic watches in 1978.

The total number of loons seen migrating through Simpson Lagoon was low both in 1977 (86 westbound birds seen during 38.6 h of systematic observations--Table 11) and in 1978 (Table 10). Even if the migration rates shown in Table 11 are extrapolated to the entire 21 August-22 September 1977 period, only about 1600 loons are estimated to have flown west within sight of an observer on Pingok Island. This estimate is very imprecise because it is based on a small sample and assumes that loons migrated at the same rate by night as by day. The rates of loon migration along the Yukon coast in 1972 were even lower; indeed, more loons were seen to fly east than to fly west (Table 11). In contrast, numbers of loons passing Point Barrow in the periods 27 August-2 September, 3-9 September and 10-16 September 1975 were estimated as 347, 7087 and 43,359, respectively (Timson 1976). These estimates also assume similar migration rates during the night as during the day. Apparently most loons bypass both the Yukon coast and Simpson Lagoon during the fall exodus from the Beaufort Sea. Offshore surveys indicate that many loons are widely distributed in offshore waters of the Beaufort Sea in August and early September (Searing et al. 1975; Divoky 1978a).

Brant. Brant migrated west through the Simpson Lagoon area in large numbers during the 22 August-6 September 1977 and 17-31 August 1978 periods (Table 10). In 1978, a few stragglers were present as late as 20 September. The timing was similar to that recorded during previous migration watches at Point Barrow in 1970 (Johnson 1971) and 1975 (Timson 1976); at Beaufort Lagoon, NE Alaska, in 1970 (22 August-10 September; peak on 1 September--Schmidt 1973); and along the Yukon coast in 1971 (most on 25 August-3 September--Schweinsburg 1974a:84) and in 1972 (most on 17 August-3 September--Gollop and Davis 1974).

Numbers of brant passing through Simpson Lagoon appeared to be at least as high as numbers passing Point Barrow. In 1977, 4231 brant were seen to fly west within sight of an observer on Pingok Island, despite the fact that there were only 22.8 h of systematic observations in the 21 August-5 September period and the fact that most of those seen were flying near the mainland shoreline near the limit of visibility from Pingok Island. In 1978, a total of 10,885 migrating brant were tallied during incidental observations, mostly from Milne Point on the mainland shore, during the

Table 11. Rates of eastward and westward 'fall' migration near the Beaufort Sea coast during three periods in late summer.

		Yukon Coast, 1972[a]				Pingok Isl., 1977[b]		
		Rate (birds/h)				Rate (birds/h)		
Species	Flight Direction	1-15 Aug	16-31 Aug	1-17 Sept	Total # Seen	21-31 Aug	1-22 Sept	Total # Seen
All Loons	E	1.15	0.86	0.40	282	0	0	0
	W	0.66	0.67	0.22	190	3.0	1.5	86
Brant	E	0	1.73	0.54	325	0	0	0
	W	0	19.21	4.92	3,526	66.4	151.0	4,231
White-fronted Goose	E	0.26	0	16.55	1,405	0	0	0
	W	0	0.10	0	16	14.3	0	270
Snow Goose	E	0	3.86	4.86	1,031	0	0	0
	W	0	174.83	2.14	28,532	0	0	0
Pintail	E	3.83	14.03	7.98	3,306	0.6	0	11
	W	3.40	0.32	0.50	419	0	0	0
Oldsquaw	E	0.81	1.02	0.17	256	0	0	0
	W	1.84	1.47	2.12	592	53.7	36.3	1,729
All Eiders	E	0.27	0.02	0	29	0	0	0
	W	0.96	0.48	0	170	27.7	0	522
All Scoters	E	0.08	0.77	1.40	250	0	0	0
	W	0.06	0.77	0.05	135	0	0	0

...continued

Species	Flight Direction	Yukon Coast, 1972[a] Rate (birds/h) 1-15 Aug	16-31 Aug	1-17 Sept	Total # Seen	Pingok Isl., 1977[b] Rate (birds/h) 21-31 Aug	1-22 Sept	Total # Seen
All Jaegers	E	0.49	0.48	0.10	133	0	0	0
	W	0.38	0.38	0.05	102	0.05	0.05	2
Glaucous Gull	E	3.90	4.73	4.67	1,529	0.1	0	2
	W	3.47	6.14	7.51	1,954	1.7	0.8	47
Thayer's/ Herring Gull	E	0.04	0.03	0.76	72	0	0	0
	W	0.02	0.03	0.13	18	0	0	0
Arctic Tern	E	1.93	1.78	0.20	489	0	0	0
	W	3.13	2.84	0	759	1.9	0	35
# Hours of Observation		95.6	162.2	83.4	-	18.[illegible]	19.7	-
# Days with Observation		15	10	8	-	10	14	-

[a] Yukon data (1972) are from watches at Nunaluk Spit (Gollop and Davis 1974) No data were obtained on 6-12 Sept. 1972. Includes all flying birds, regardless of distance from shore or visibility.

[b] Pingok Island data (1977) include all migrants regardless of distance from the island; only watches with visibility at least 3 km are considered.

17-31 August period. Undoubtedly many additional brant passed unrecorded during both 1977 and 1978. In contrast, Johnson (1971) estimated that 14,000 brant flew past an observer at Point Barrow during the 18 August-7 September 1970 period (only 1103 actually seen), and Timson (1976) estimated that 2740 brant flew past that area in the 27 August-16 September 1975 period (only 400 seen in 68 h of observations). East of Simpson Lagoon, Schmidt (1973) saw 12,910 brant fly west along Beaufort Lagoon on 22 August-10 September 1970, and Schweinsburg (1974a) saw 14,806 fly west past Nunaluk Spit, Y.T., during 150 h of observations on 25 August-6 September 1971. However, Gollop and Davis (1974) saw only 3526 fly west past Nunaluk Spit during intensive watches in 1972 (Table 11). These results suggest that brant nesting to the east of the study area migrate westward in a concentrated stream close to the Beaufort Sea coast, and thus pass through Simpson Lagoon.

Oldsquaw. Oldsquaws were seen migrating west through Simpson Lagoon in late August and intermittently throughout September 1977. However, very large numbers remained in the lagoon as late as 22-23 September in 1977-79 (Table 9). The seasonal trends in numbers, sex ratios and age ratios of oldsquaws in the lagoon suggested that in 1977 and 1978, post-molting male oldsquaws began to leave the lagoon during August. Many males were still present in September, but in addition large numbers of post-breeding females and juveniles moved into the lagoon late in the summer (see 'MOLTING' section). Thus there was considerable turnover of oldsquaws using the lagoon in the August-September period. About 250 oldsquaw were still present in an area of open water east of the ARCO causeway in Prudhoe Bay on 15 October 1978.

If the rates of migration recorded during our rather small number of watches (Table 11) apply to the entire 21 August-22 September 1977 period (including nighttime hours), about 33,000 oldsquaws flew west within sight of an observer on Pingok Island during this period. However, an estimated 106,600 oldsquaws remained in Simpson Lagoon itself on 22 September 1977, and additional oldsquaws were presumably present further east at that time (see 'MOLTING' section, below). Thus the total number that passed through Simpson Lagoon in the fall of 1977 may have been much more than 100,000. Much of the migration from (and perhaps much of that through) the lagoon occurred after our systematic observations ended. Timson (1976) estimated that about 32,000 and 208,500 oldsquaws passed an observation point at Point Barrow in the 3-9 and 10-16 September 1975 periods, respectively. Presumably more oldsquaws passed after her study ended.

No systematic fall migration watches were conducted at Simpson Lagoon in 1978, but no significant westward migration of oldsquaws was noticed during casual observations in August and September. Trends in numbers and sex ratios (see 'MOLTING') indicated that movements must have occurred, but they were not conspicuous and there is no proof that the birds moved westward along the coast. Similarly, few oldsquaws migrated west along the Yukon coast during systematic watches on 24 August-6 September 1971 (997 seen in 156 h--Schweinsburg 1974a) or up to 17 September in 1972 (Table 11). Oldsquaws do occur far offshore in the Beaufort Sea during late August and September (Searing et al. 1975:224; Divoky 1978a:407, 419, 432). Thus it is probable that a significant fraction of the autumn oldsquaw migration is not near the coast.

Eiders. Eiders migrated west through Simpson Lagoon in small numbers during late August of 1977 and 1978 (Table 10, 11). Only 522 were seen during 38.6 h of systematic watches from Pingok Island on 21 August-22 September 1977. Although eider migration was not noted during early or mid-September, small numbers of eiders remained in Simpson Lagoon and Harrison Bay as late as 22-23 September in 1977-79 (Table 9). Similarly, little eider migration was noted along the Yukon coast in August or September of 1971-72 (Schweinsburg 1974a; Gollop and Davis 1974).

In contrast, large numbers of female eiders and (after late August) young-of-the-year pass Point Barrow during late summer. Timson (1976) estimated that about 113,000 eiders passed her observation site in the 27 August-16 September period (14,625 actually seen in 68 h).

The above results suggest that many post-breeding and juvenile eiders bypass Simpson Lagoon during fall migration. It is unclear what route these birds follow. Some eiders are seen in relatively shallow waters of the southern Beaufort Sea beyond the barrier islands in late summer (Table 9; see also Bartels 1973; Watson and Divoky 1974; Divoky 1978a). However, densities farther offshore are very low (Searing et al. 1975; Harrison 1977; Divoky 1978a).

Phalaropes. Few phalaropes were seen in active fall migration, although premigratory staging phalaropes were abundant along the Jones Islands during mid to late August of 1977 and 1978 (see 'PREMIGRATORY STAGING' section). All phalaropes collected in the Simpson Lagon area in August were young-of-the-year. Peak numbers along the shorelines of Simpson Lagoon were about 6100 on 16 August 1977 and 2475 on 29 August 1978. Northern phalaropes were much less abundant than red phalaropes.

The majority of the phalaropes had departed by early September. However, during 1977 some flocks were observed in the study area as late as 14 September. Although no phalaropes were recorded in the study area after 3 September 1978, a flock of approximately 400 was recorded in the Sagavanirktok River delta on 23 September 1978, and two small flocks of four and eight phalaropes were seen in an area of open water along the east side of the ARCO Causeway (Prudhoe Bay) on 14 and 15 October 1978, respectively.

Jaegers. Almost no jaegers were seen to migrate through Simpson Lagoon in late summer (Table 10, 11). There was also no clear westward migration along the Yukon coast in August-September of 1971 or 1972, and few jaegers pass Point Barrow at this time (Johnson 1971; Timson 1976). Jaegers are apparently widely distributed in nearshore and offshore waters of the Beaufort Sea in August and early September (Frame 1973; Harrison 1977; Divoky 1978a).

Glaucous Gull. Little westward movement of glaucous gulls through Simpson Lagoon was evident up to the end of regular observations around 22 September in 1977 and 1978. In all years (1977-79) the numbers of glaucous gulls present in the lagoon area increased during September (Table 9; see 'PREMIGRATORY STAGING' section, below). In 1972, westward migration along the Yukon coast began in mid-September (Gollop and Davis 1974). It is probable that there was considerable migration through Simpson Lagoon in late September and October (*cf.* Bailey 1948). However, glaucous gulls are also common in offshore waters of the western Beaufort Sea in late summer (Frame 1973; Watson and Divoky 1974; Divoky 1978a). Thus it is probable that many fall migrants bypass Simpson Lagoon.

Arctic Tern. Terns began to move west through Simpson Lagoon in mid-August of 1977. Large noisy flocks of adults and juveniles were observed moving westward at high altitudes along the Jones Islands (Table 10). The fall migration of arctic terns had terminated by 30 August 1977. Possibly because the field camp was situated on the mainland and because systematic migration watches were not conducted during fall 1978, no such movement of arctic terns was noted during fall 1978. Terns also moved west along the Yukon coast in mid and late August of 1972 (Gollop and Davis 1974; Table 11). At Point Barrow, fall migration of terns was mainly in August during 1976 (Connors and Risebrough 1977:444; Divoky 1978a: 489), but some terns were present in early September. Timson (1976) estimated that 1879 terns passed her observation site at Point Barrow in the 27 August-16 September 1975 period. Although the highest densities of terns are found near the barrier islands during the late summer period (Table 9; see also Harrison 1977; Divoky 1978a), some terns do occur far offshore at this time (Divoky 1978a).

Species Noteworthy for their Scarcity. Several species that might be expected to be common fall migrants through Simpson Lagoon were not (Table 10). Some of these species were common migrants or summer residents at Simpson Lagoon earlier in the season, but were uncommon transients during late summer (e.g., white-fronted geese, pintails, scoters, jaegers, Sabine's gulls). Some of these species, and some others, are common fall migrants elsewhere in the North Slope area but not over the nearshore waters of Simpson Lagoon.

Snow and white-fronted geese, pintails and scoters are common fall migrants along the Yukon coast but not at Simpson Lagoon (Table 11). Most of these species migrate through the Brooks Range in small numbers (Irving 1960). However, their main fall migration routes out of the Beaufort Sea area are up the Mackenzie Valley (Campbell 1973; Salter 1974; Bellrose 1976; Koski 1977).

Sabine's gulls, on the other hand, are common during late summer at Point Barrow (Seale 1898; Bailey 1948; Bee 1958; Timson 1976; Connors and Risebrough 1977; Divoky 1978a), but are not common at this time either at Simpson Lagoon or along the Yukon coast. They are widely distributed in offshore waters of the western Beaufort Sea in late summer (Frame 1973;

Watson and Divoky 1974; Divoky 1978a), so it is probable that their westward fall migration from the Beaufort Sea area is largely through offshore waters.

Most Thayer's gulls have been presumed to migrate through the Beaufort Sea while en route between their breeding areas in the Canadian arctic islands and their wintering areas along the Pacific coast (e.g., Watson and Divoky 1974). Those authors saw only a few offshore in the western Beaufort Sea in late summer, and suggested that most may move through inshore waters. Some Thayer's gulls have been collected in northwest Alaska in fall (Bailey 1948), but there is no evidence of a significant westward movement near the Yukon coast or in the Simpson Lagoon area, at least up to the third week of September (Table 11).

In summary, the most abundant late summer and fall transients in Simpson Lagoon are brant, oldsquaws, phalaropes and, to a lesser degree, arctic terns. Numerous loons and eiders also move through the lagoon, but the numbers involved are small relative to known population sizes. Glaucous gulls probably migrate through the lagoon in large numbers in fall, but most of this migration occurs after our systematic studies ended (i.e., after 22 September). Snow geese, white-fronted geese, pintails, scoters, jaegers, Thayer's gulls and Sabine's gulls are all only scarce migrants in nearshore areas during late summer and fall.

Discussion

Migration is inherently a large scale phenomenon. To understand migration patterns in a small area such as Simpson Lagoon, it is necessary to consider migration patterns and environmental conditions over a much larger area.

Spring Migration

The Beaufort Sea is largely ice-covered during spring migration. However, some areas of open water do exist, and many of these are quite consistent from year to year. The existence of recurring areas of open water and recurring patterns of ice break-up has undoubtedly had profound influences on the development of waterbird migration routes and timing in the Beaufort Sea area.

Spring Ice Conditions. Ice conditions in the Beaufort Sea have been studied intensively in recent years. The following description is based on Markham (1975), Marko (1975), Shapiro and Barry (1978) and Dey et al. (1979), as well as our own analyses of aerial survey data and interpretation of satellite imagery (Richardson et al. 1975; Searing et al. 1975).

Even during the early part of arctic spring (April), a lead is present just beyond the edge of the narrow shelf of landfast ice bordering the Chukchi coast of northwest Alaska. Thus open water is present as far to the northeast as Point Barrow. East from there to the Tuktoyaktuk Peninsula, N.W.T., an unbroken and generally broad sheet of landfast ice covers the nearshore waters of the southern Beaufort Sea. Currents and winds cause leads and cracks to form and disappear on an irregular schedule along the northern edge of this landfast ice and in the heavy pack ice to the north. Thus there are usually some small areas of open water far offshore in the Beaufort Sea during early spring, but their positions are predictable in only a general way. However, along the eastern edge of the Beaufort Sea--just west of Banks Island and north of the Bathurst Peninsula--areas of open water are quite dependably present even in early spring. Some of these areas are no more than 30 m deep, which is within the diving range of oldsquaws and possibly eiders (Palmer 1976; Peterson and Ellarson 1977).

Thus, open water is dependably present in early spring off northwest Alaska (NE to Point Barrow) and in the extreme eastern part of the Beaufort Sea. In the intervening area (which is 1000 km wide), small areas of open water are usually present in the pack ice far offshore, but nearshore areas are covered by thick landfast ice.

During May and the first half of June, the period of peak spring migration, the same general pattern prevails. However, areas of open water become somewhat more extensive:

- Leads tend to become commoner and larger.
- The areas of open water in the eastern Beaufort Sea become very extensive and expand westward, particularly when the spring flood of water from the Mackenzie River reaches the sea in late May and June (Davies 1975).
- River and stream runoff onto the landfast ice along the Alaskan and Yukon coasts initially produces areas of freshwater on top of the ice (e.g., Walker 1974). Ice melt is

> rapid in these areas, so shoreleads form off river mouths during June--well before most of the landfast ice breaks up.

Thus, during the peak of spring waterbird migration, an extensive area of open water in the eastern Beaufort Sea is still separated from open water near Point Barrow by a large area where the only open water is in leads far offshore and (after early June) in local areas at the mouths of rivers.

In the Simpson Lagoon area, landfast ice extends northward at least 25 km from the barrier islands during spring (W.J. Stringer, in Shapiro and Barry 1978:19). The northern edge of the landfast ice is oriented WNW-ENE, parallel to the general trend of the Beaufort Sea coast of Alaska. River and stream water flows out onto the ice of Simpson Lagoon from the Kuparuk River and smaller streams during the first two weeks of June (Schamel 1978; this study). In early June of 1977 and 1978, water from the Colville River covered an extensive area in Harrison Bay, but did not flow into Simpson Lagoon. In mid June, the landfast ice lifted from the bottom of Simpson Lagoon (see Griffiths and Dillinger 1980), and shoreleads began to form along the barrier islands (both sides) and mainland. In early to mid July, the lagoon ice broke up and moved out of the lagoon into Harrison Bay, which by this time was also breaking up. Ice in the nearshore Beaufort Sea north of the barrier islands often does not break up until several weeks after that in the lagoons.

The mainland tundra in the Simpson Lagoon-Prudhoe Bay area remains largely snow covered until late May, and snowmelt proceeds rapidly in early June. Snowmelt begins earlier on inland portions of the North Slope despite the higher elevations inland (Benson et al. 1975; Holmgren et al. 1975). The prevailing ENE onshore winds cause temperatures to be lower along the coast than inland (Brown et al. 1975; Walker and Webber 1979).

Eastward Migration along the Coast. Along the northwest coast of Alaska, where open water occurs rather close to shore during spring, very large numbers of waterbirds can be seen migrating northeast over nearshore waters (Gabrielson and Lincoln 1959; Johnson 1971). East of Point Barrow, there is also a conspicuous eastward migration of waterbirds near the icebound coast. However, it has long been evident that, for most species, the numbers migrating along the coast east of Barrow are comparatively low (Brooks 1915; Irving 1960:275). Observations from islands and points of land have suggested that much of the migration, especially in early spring, occurs too far offshore to be seen from land (Anderson 1937:118; Barry 1972; Schamel 1978).

This study and an earlier one conducted in 1975 provide the first systematically-derived estimates of numbers of waterbirds migrating along the Alaskan or Yukon coasts of the Beaufort Sea in spring. Table 4 provides such estimates for both the Simpson Lagoon area and the Yukon coast. Some of the noteworthy results are the rather low estimated numbers of certain species passing through the Simpson Lagoon area in the spring of 1977: only about 1200 loons, 2100 brant (probably more in 1978), 10,000 oldsquaw, 4800 eiders, 11 Sabine's gulls, and 130 arctic terns. These estimates are imprecise, for reasons already mentioned, and include only low-altitude visible migration. However, they are based on a considerable volume of systematically-collected data, and are comparable in reliability to previous summer and fall results from Point Barrow (Thompson and Person 1963; Johnson 1971; Timson 1976). Consistent with our low estimates, radar shows that the eastward migration past Simpson Lagoon in spring is broad-front in character, with little concentration near the rather irregular-shaped coast.

During late May and the first half of June, the Oliktok radar routinely shows an eastward broad-front migration over the North Slope (Fig. 3, 8, 9; see also Flock 1973). Eastbound migrants are usually present to the limits of radar detectability 50-75 km inland. The species composition of these migrations is not adequately known, but visual observations from the coast indicate that many brant and some jaegers fly over portions of the tundra within a few kilometers of the coast.

Farther east, along the coast of the northwestern Yukon Territory, both visual and radar evidence show that more of the eastbound migrants are narrowly concentrated along the coast. Migrants that were markedly more abundant there than at Simpson Lagoon included brant (about 26,000 vs 2100 estimated) and arctic terns (about 790 vs 130). However, loons, oldsquaws and eiders, which are known to be abundant migrants in the Beaufort Sea area (Johnson 1971; Timson 1976), were seen in only modest numbers along the Yukon coast.

Counts from Cape Dalhousie at the top of the Tuktoyaktuk Peninsula in the SE Beaufort Sea also revealed only modest numbers of eastbound loons, oldsquaws and eiders. The numbers seen passing within 1.6 km of the observer during daily watches of 12-h duration during 29 May-16 June 1972 totalled only 275, 1507 and 1659, respectively (Barry 1972). Only 192 jaegers, 354 glaucous gulls, 64 Sabine's gulls and 23 arctic terns were reported at Cape Dalhousie.

Thus there is an important broad-front eastward migration over the arctic coastal plain and southern Beaufort Sea during spring, but the coast itself does not form a major route for narrow-front eastward migration, at least in the Simpson Lagoon area. The many eastbound waterbirds visible to a coastal observer represent only a small portion of the total eastward movement. The brant is the only bird whose Beaufort Sea population appears to be highly concentrated anywhere along the coast during spring migration, and this concentration is along the Yukon coast, not at Simpson Lagoon.

The lack of concentration along the coast in the Simpson Lagoon area during spring presumably is attributable to (1) the presence of a continuous sheet of landfast ice over nearshore waters, (2) the irregularity of the coast (poor leading line), and (3) the great width of the arctic coastal plain (little funneling effect). Even after river water overflows onto the ice in early June, access to marine food resources is blocked by the underlying ice. Little or no food is accessible to waterbirds in nearshore areas until shoreleads form in mid June. Only then do birds gain access to the amphipods, mysids and fish that recolonize the shallow waters during mid to late June (Griffiths and Dillinger 1980; Craig and Haldorson 1980).

Some waterbirds (especially brant) did land on the river water present on top of the lagoon ice in early June 1977. It is unlikely that any significant amount of food was available to these birds, although two yellow-billed loons were seen to dive into this water on 8 June 1977.

Eastward Migration Offshore. Visual and radar observations at Point Barrow suggest that, after passing that location, most eiders fly ENE toward the offshore waters of the Beaufort Sea (Flock 1973). There have been no systematic observations offshore in the Alaskan Beaufort Sea during spring, but in 1974 large numbers of eiders and oldsquaws appeared in the leads and polynyas of the eastern Beaufort Sea during May (Searing et al. 1975).

Indeed, Inuit have reported that some oldsquaws, common eiders and king eiders are present at the floe edge off SW Banks Island in April (Manning et al. 1956).

Extensive aerial surveys of the Canadian Beaufort Sea in the springs of 1974 and 1975 showed that loons (especially yellow-billed), brant and glaucous gulls were also widely distributed in small numbers far offshore (Searing and Richardson 1975*; Searing et al. 1975; Richardson et al. 1975; Barry 1976a). These species, as well as eiders and oldsquaws, probably migrate eastward through offshore portions of the Beaufort Sea. However, jaegers were scarce, arctic terns were almost absent, and Sabine's gulls were not seen. Aerial surveys in the Baffin Bay area of the eastern arctic during the spring migration period have shown higher densities of migrating jaegers near the floe edge than over pack ice or open water farther offshore. However, migrating arctic terns in the eastern arctic are widely distributed over offshore areas (Johnson et al. 1976; McLaren and Renaud 1979).

In the absence of aerial survey or other data from offshore waters of the Alaskan Beaufort Sea in spring, patterns of waterbird migration are highly uncertain. Inferences about the species composition, timing and certain characteristics of the movements can be made from observations at Point Barrow, in the Canadian Beaufort Sea, and elsewhere. However, the specific routes, stopover locations (if any) and numbers of migrants in offshore waters are unknown. Radar observations from the coast (Flock 1973; Richardson et al. 1975; this study) show that there is broad front movement to the E and ESE over the landfast ice zone and at least the southern edge of the pack ice (Fig. 8). Visual observations suggest that oldsquaws, eiders, loons and glaucous gulls are the main species moving east over the landfast ice north of the barrier islands (Table 4, column G; Schamel 1978). However, neither island-based observers nor coastal radars can detect the low-altitude flights that probably occur along and beyond the floe edge. The apparent decrease in frequency and density of eastward migration with increasing distance from shore (Fig. 8) may be an artifact of the reduced ability of the radars to detect birds at increasing distances.

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*This unpublished report includes maps of sightings for some species not mapped in the published version.

There have been both radar and visual observations of birds approaching the North Slope from the north in spring (Flock 1973; Richardson et al. 1975; Schamel 1978). Schamel's visual observations involved red phalaropes. It is possible that some waterbirds that nest on the Alaskan North Slope migrate over offshore areas, and remain offshore until snow melt occurs on land or until river runoff produces shoreleads in the nearshore landfast ice.

Northeast and North Migration through Interior Alaska. The offshore and coastal routes discussed above are not the only routes by which waterbirds wintering in Alaskan or Pacific waters reach the Beaufort Sea. Radar observations in the northern Yukon show that some birds fly northeast from interior Alaska, across the North Slope of extreme NE Alaska and the Yukon, and out over the Beaufort Sea (Fig. 8; details in Richardson et al. 1975). Such flights were detected as early as 12 May. Some brant (Cade 1955; Irving 1960) and jaegers (Dean et al. 1976; B. Kessel pers. comm. 1978) are known to follow such a route, at least as far as the North Slope, during late May and June. However, it is unlikely that brant or jaegers were responsible for the northeastward migration detected by radar in mid-May.

Other species present offshore in the Canadian Beaufort Sea in mid to late May are oldsquaws, common and king eiders, and glaucous gulls. There is no direct evidence that members of any of these species fly NE across interior Alaska and then out into the Beaufort Sea, but the radar evidence suggests that some must do so.

Oldsquaws seem to be the most likely possibility. They migrate through interior Alaska and the Yukon in at least small numbers (Kessel and Cade 1958; Irving 1960), and during spring they are known to migrate overland for long distances, mostly at high altitudes, in northern Europe (Bergman and Donner 1964; Bergman 1974, 1977) and in central North America (Bellrose 1976).

Eiders are not known to migrate in significant numbers across interior Alaska, but they are not always confined to coastal and offshore routes. Some cross the Seward Peninsula and the tundra south of Barrow during spring (Myres 1958; Johnson 1971; Flock 1973; Palmer 1976). There are well-documented overland migrations of common eiders in eastern North America

(Gauthier et al. 1976), Denmark (Schmidt 1976), and southern Sweden (Swegen 1972; Alerstam et al. 1974). In the Swedish case, most of the eiders were already at heights of 200-450 m AGL (maximum 800 m) after travelling at most 50 km overland (Karlsson 1976). Many king eiders are known to fly overland across Baffin Island during their molt migration (Wynne-Edwards 1952). There is circumstantial evidence of a long (1200 km) non-stop spring migration of common eiders from western Norway across the Scandinavian mountains, the frozen Gulf of Bothnia, and Finland to the White Sea (Folkestad and Moksnes 1970; Bergman 1974:133). Radar data show that, over the Gulf of Bothnia, the birds presumed to be eiders are at altitudes of 1500 to 2000 m or more. Thus it is possible, on the basis of eider behavior elsewhere, that some eiders fly non-stop and unseen over Alaska to the eastern Beaufort Sea.

Some glaucous gulls migrate through interior Alaska in spring (Kessel and Cade 1958; Irving 1960). However, it is doubtful that they fly fast enough to account for the fast-moving flocks of birds detected migrating NE over the northern Yukon in May 1975.

Some other waterbirds also bypass much or all of the Alaskan portion of the Beaufort Sea and take a more direct overland route to NE Alaska or the western Canadian arctic. Some arctic loons, yellow-billed loons, and perhaps arctic terns fly overland along this route (Kessel and Cade 1958; Irving 1960; Kessel and Schaller 1960; Palmer 1962; Griffiths 1973). Some of these species nest in the interior as well as along the arctic coast, so it is uncertain how many continue on to the coast. However, arctic loons are known to undertake long overland migrations in Europe (Schüz 1974; Cramp and Simmons 1977), and some arctic terns apparently fly overland to the James Bay area (Godfrey 1973). In view of their scarcity in the Alaskan Beaufort Sea in spring, many Thayer's and perhaps Sabine's gulls may also fly overland.

Many other waterbird and shorebird species that are summer residents of the North Slope also fly north through the interior of Alaska. These include snow, Canada and white-fronted geese, pintails, scoters and various shorebirds (Kessel and Cade 1958; Kessel and Schaller 1960; Irving 1960). Some of these species are common on tundra and freshwater habitats north to the coast of the Beaufort Sea, but these species do not move north into the Beaufort Sea itself during spring. Derksen and Eldridge (1980) discuss the status of the pintail on the North Slope.

Northwestward Migration into Arctic Alaska. Irving (1960:276) stated that 'there are no reports known to me which indicate that spring migration passes westward from Mackenzie to the arctic coast of Alaska'. Recent studies in northwestern Yukon have shown that significant numbers of whistling swans and pintails fly west into Alaska along the coast; small numbers of white-fronted, snow and Canada geese also follow this coastal route (see Table 4, based on data of Johnson et al. 1975; see also Brooks 1915; Schmidt 1973; Gollop and Davis 1974:161).

All five of these waterfowl species apparently also migrate west in spring through interior portions of the Yukon coastal plain (Salter et al. 1980). Many if not all of the whistling swans nesting on the Alaskan North Slope are members of the Atlantic-wintering population (Sladen 1973), and thus are likely to migrate W and NW from the Mackenzie Valley rather than through the interior of Alaska. The other four species listed above migrate north through interior Alaska as well as W along the coast. None of these five species uses marine habitats to any significant degree.

Bellrose (1976) indicates that over 10,000 snow geese migrate west along or near the Beaufort Sea coast from the Mackenzie Delta to Point Barrow and onward to Wrangel Island, U.S.S.R. We know of no observational evidence of such a migration.

The five waterfowl species discussed above migrate west along the Yukon and Alaskan North Slope in only small to moderate numbers. The numbers of westbound migrants seen visually are quite inconsistent with the nearly continuous and broad-front westbound migration detected by radar during spring (Fig. 4, 8, 10). From mid June onward, westward molt migration of seaducks (oldsquaws, eiders, scoters) no doubt accounts for much of the westward migration evident on radar. In some years (e.g., 1975) there is also a conspicuous westward migration of non-breeding jaegers away from their nesting areas in mid and late June (see Fig. 6 and Maher 1974). These movements may account for the increase in the rate of westward migration as June progresses (Fig. 4), but they do not account for the westward migrations in late May and early June.

Shorebirds are likely responsible for much of the west and WNW migration detected by radar during spring. Of five sandpiper species listed as abundant at Prudhoe Bay, Barrow, or both by Norton et al. (1975), four species--the semipalmated, Baird's, pectoral and buff-breasted sandpipers--migrate to northern Alaska from the interior of the continent (Palmer 1967; Martinez 1974, 1979; Harrington and Morrison 1979; Jehl 1979; Lank 1979). American golden plovers and long-billed dowitchers as well as pectoral sandpipers are conspicuous eastbound migrants in the northern Yukon during late summer (Campbell 1973; Gollop and Davis 1974; Vermeer and Anweiler 1975; Salter et al. 1980), and some likely migrate WNW through northern Alaska in spring. All six of these species are common at Anaktuvuk Pass in spring (Irving 1960), so it is likely that only a fraction of the individuals nesting in northern Alaska migrate WNW or W along the North Slope. Some pectoral sandpipers and long-billed dowitchers migrate west from Alaska to breeding areas in Siberia (Houston 1965; Palmer 1967; Martinez 1979), although not necessarily through northern Alaska. Shorebirds are normally very inconspicuous during their long distance migrations, which often occur at high altitudes (see Richardson 1979 for review). Thus they are likely to be much more prominent on radar than visually. Sandpipers and plovers do not use shoreline habitats along the Beaufort Sea in spring.

Attraction to Open Water. The timing and routes of spring waterbird migration into and through the Beaufort Sea are strongly influenced by seasonal patterns of availability of open water, on which marine waterbirds depend for access to food. Open water is a scarce commodity in spring, and the evidence indicates that migrating waterbirds can be expected to land on any available open water in nearshore areas (this study; Bergman et al. 1977; Schamel 1978). Thus, it is almost certain that some waterbirds would be contaminated if oil or another contaminant were present during spring in any nearshore area with open water.

A further cause for concern is that some birds appear to be attracted to pools of oil on top of ice, presumably mistaking the oil for open water (Dubrovsky 1959; Barry 1970, 1976b). Such pools could occur not only if oil is spilled onto the ice from above, but also when oil that has accumulated under the ice in winter migrates upward through the melting ice in spring (Lewis 1978). The situation would be especially serious in a heavy-ice year when there is little or no open water offshore in the Beaufort Sea. Waterbirds are severely stressed in such years (Barry 1968), and would be expected to concentrate even more than usual in any available area of open water (Barry 1976b). Birds presumably would be especially likely to land in pools of oil if little or no open water were present.

Molt Migration

The summer molt migration of adult male eiders past Point Barrow is well known from the work of Thompson and Person (1963), Johnson (1971) and others. The molt migrations of oldsquaws and scoters are much less well documented. Indeed, even in the case of eiders there are important gaps in knowledge.

Eiders. Systematic observations at Point Barrow began on 14 July in 1953 (Thompson and Person 1963) and on 13 July in 1970 (Johnson 1971). The westward migration of eiders at Simpson Lagoon begins in early July (Fig. 16), and at Barrow the duck camp became active about that time in 1970 (Johnson 1971:6). Thus the earliest stages of the molt migrations have not been included in previous studies.

The routes of westbound eiders in areas east of Point Barrow are poorly known. Anderson (1937) reported a large flight past the tip of the Bathurst Peninsula in mid July of 1912; he does not give total numbers, but the implication is that many thousands were seen. In contrast, few eiders move west along the Yukon coast in July (Fig. 16), and Brooks (1915) and Schmidt (1973) imply that only modest numbers move west along the coast of NE Alaska. Our results show that the numbers migrating through Simpson Lagoon in July are in the thousands, in contrast to the hundreds of thousands that pass Point Barrow at this time. Similarly, Hall (1975) and Schamel (1978) observed no major westward migration of eiders through nearshore waters in the Simpson Lagoon area. Thus, there is no evidence of a concentrated westward molt migration of eiders along the south-central coast of the Beaufort Sea (Simpson Lagoon to Mackenzie Delta). Major westward molt migration is apparently evident at Cape Bathurst, N.W.T., in the SE Beaufort Sea, as well as at Point Barrow.

Radar evidence about the routes of the eiders is, for the most part, inconclusive. During early July, broad-front WNW migration occurs over the North Slope and southern Beaufort Sea around the Yukon-Alaska border (Richardson et al. 1975). However, scoters and perhaps oldsquaw must account for at least a portion of that movement. During late July, on one occasion of major westward eider migrations (numbers unstated) along the coast past Lonely, Alaska (approximately 130 km west of Simpson Lagoon), Lonely radar showed an intense broad-front westward migration over the coastal plain (Flock 1973). However, in neither of these studies is it known that eiders were the birds responsible for the broad-front movements. Eiders engaged in molt migration do fly overland at Baffin Island (Wynne-Edwards 1952) and in Denmark (Salomonsen 1968; Schmidt 1976); overland migrations by eiders at other seasons were mentioned earlier.

Radar observations at Point Barrow indicate that most eiders approach the point in a rather narrow stream along the shore or barrier islands; their flight direction is about 290° as they approach the point, and gradually changes to 250° west of the point (Flock 1973).

An aerial survey of the Canadian Beaufort Sea during 3-7 July 1974 showed that eiders were present as far as 115 km from shore, although most of those seen were less than 60 km offshore (Searing et al. 1975:231). A total of 721 eiders were seen along about 4200 km of transects ($0.44/km^2$). The numbers present offshore decreased during surveys later in July. Surveys offshore in the Alaskan Beaufort Sea during the summer have shown that few eiders are present in offshore waters (Bartels 1973; Frame 1973; Harrison 1977; Divoky 1978a). However, most of these surveys of Alaskan offshore waters were conducted after the period of peak molt migration by male eiders.

The relative abundances of common and king eiders during molt migration vary markedly from place to place. At Point Barrow, 95% of the westbound eiders seen and 95% of the eiders shot from mid July to early September 1970 were king eiders (Johnson 1971). King eiders also predominate in other years (Thompson and Person 1963). However, at Simpson Lagoon king and common eiders comprised 42% and 58%, respectively, of the 4711 westbound eiders that were specifically identified in the 26 June-31 July period of 1977 and 1978 (Table 7). If only the westbound eiders seen during systematic watches

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at Simpson Lagoon are considered, the percentages are 62% king and 38% common (Table 6). Westbound spectacled and Steller's eiders together comprise less than 1% of the flight at both Point Barrow and Simpson Lagoon. At Cape Bathurst, Anderson (1937) found that king eiders predominated initially, but by 18 July 'there were about as many Pacific [Common] Eiders as King Eiders'. Of the 840 eiders identified during aerial surveys of the southeastern Beaufort Sea in July 1974, 51% were king and 49% common (Searing et al. 1975:20).

The total number of common eiders in the Beaufort Sea area is not well known. T.W. Barry estimated that a fourth of the eiders there, or about 275,000, are common eiders (cited in Bellrose 1976:356). Over 75,000 common eiders were seen in a single lead in the eastern Beaufort Sea on 21 May 1974 (Searing et al. 1975:126). Thus the relative abundances of king and common eiders at Point Barrow during the summertime molt migration appear atypical of those elsewhere in the Beaufort Sea area. Some common eiders remain in the Beaufort Sea area to molt (Höhn 1955; Smith 1973; Ward 1979). Even if more common than king eiders molt in the Beaufort Sea, it is noteworthy that the king:common ratio is much higher during molt migration at Point Barrow than at Simpson Lagoon or Cape Bathurst.

Oldsquaw. This study provides the first systematic documentation of the westward molt migration of male oldsquaws along the Alaskan north coast. There were previous observations of this migration (see below), but its magnitude has not been documented before. Similarly, there are few well-documented cases of molt migrations of oldsquaws elsewhere in their circumpolar range (Salomonsen 1968; Palmer 1976; Cramp and Simmons 1977). The best known case is a northward molt migration of oldsquaws from eastern Siberia to Wrangel Island (Salomonsen 1968).

During the systematic migration watches at Point Barrow, very few oldsquaws have been seen moving west before late August (Johnson 1971; *cf.* Thompson and Person 1963; Timson 1976). In the Simpson Lagoon-Prudhoe Bay area, several previous authors have mentioned the build up of molting oldsquaws along the coast during summer, but the existence of a major westward migration has not been mentioned (Hall 1975; Gavin 1976; Schamel 1978). Farther east, near the Alaska-Yukon border, westward migration of oldsquaws has been noted in late June and July (Brooks 1915; Schmidt 1973; Gollop and Davis 1974). Similarly, Anderson (1937) saw a few oldsquaws moving west at Cape Bathurst, N.W.T., in mid July.

The peak of the molt migration through Simpson Lagoon in 1977 and 1978 was in the first half of July, with a secondary, smaller peak later in July (Fig. 16). The systematic migration watches at Point Barrow did not begin until mid July, so the first peak might have been missed there. However, Divoky (1978a:482) did not record a westward molt migration through Elson Lagoon in late June or early July of 1976. It seems highly unlikely that any major westward movement in late June or early July could have passed unnoticed by Divoky (1978a) and the numerous other investigators who have worked at Barrow.

Thus it is probable that the oldsquaws that move west through Simpson Lagoon in early July either remain in the western Beaufort Sea to molt, or bypass Point Barrow. Many oldsquaws are present between Simpson Lagoon and Barrow during July and August, the molt and post-molt periods (this study; Divoky 1978a:432). However, scattered groups of oldsquaws are also present in offshore waters of the western Beaufort Sea in July (Harrison 1977:422). This suggests that some molt migrants do not follow the coast, and thus may bypass Point Barrow. The ability of oldsquaws to dive to great depths (perhaps as deep as 60 m--Palmer 1976), together with the shallowness of much of the southern Beaufort Sea, would allow oldsquaws to feed on benthic organisms even during migration across areas far from shore.

The numbers of oldsquaws seen migrating west along the Yukon coast in late June and July of 1972 and 1974 (Fig. 16) are much too low to account for the arrival of tens of thousands of oldsquaws in lagoons and bays along the north coast of Alaska during July (see 'MOLTING' section, below). A high percentage of the male oldsquaws that appear along the Alaskan coast probably move to the sea from adjacent breeding areas on the mainland. Those that migrate west through the lagoon in early summer may be engaged in a short-distance molt migration within the Alaskan Beaufort Sea region. However, oldsquaws were also widely distributed in small numbers in offshore waters of the eastern Beaufort Sea in late June and early July of 1974 and 1975 (Richardson et al. 1975; Searing et al. 1975). Although ice conditions in 1974 were atypically severe, these results and the previously mentioned sightings offshore in the western Beaufort Sea in July (Harrison 1977) suggest that there may be a significant westward molt migration of oldsquaws over offshore waters.

Scoters. Surf and white-winged scoters are common nesting birds north to the Mackenzie Delta (Porsild 1943; Cowan 1947; Martel 1975). They also nest sparingly in the interior of northern Alaska (Irving 1960), but not to any significant extent along the arctic coast. The black scoter is uncommon in the Beaufort Sea area even as a non-breeding visitant.

Male scoters begin to move west across the Mackenzie Delta in mid June (Porsild 1943), and move west along the Yukon coast into Alaska in late June and July (Fig. 16; see also Andersson 1973; Gollop and Davis 1974). Surf scoters and smaller numbers of white-winged scoters were common molt migrants at Simpson Lagoon in 1978, although not in 1977. Few scoters move west as far as Point Barrow. Fewer scoters occur in the Simpson Lagoon-Prudhoe Bay area during the molting period than occur along the coast of extreme northeastern Alaska and the northern Yukon; especially large numbers molt near Herschel Island, Y.T. (4500 estimated by Vermeer and Anweiler 1975; see also Andersson 1973; Gollop and Richardson 1974; Gollop, Goldsberry and Davis 1974a; Ward and Sharp 1974; Salter et al. 1980). Even larger concentrations may occur just east of the Mackenzie Delta (Barry 1972; Searing et al. 1975:131).

Some scoters appear in leads and polynyas of the eastern Beaufort Sea as early as late May (Johnson et al. 1975; Searing et al. 1975). It seems likely that these are immature or non-breeding birds, which sometimes continue northward beyond the breeding range (Palmer 1976:303).

The molt migrations and other movements of scoters in North America are poorly understood (Bellrose 1976; Palmer 1976). The west and northwest molt migration along the south coast of the Beaufort Sea is now one of the best-known examples of molt migration in North American scoters. This movement, unlike the molt migrations of eiders and oldsquaws in the Beaufort Sea area, is in a direction contrary to the fall migration. In contrast, the well-known molt migrations of black and white-winged scoters in northern Europe are generally toward the wintering areas (Salomonsen 1968; Bianchi and Krasnov 1976; Schmidt 1976; Viksne and Baumanis 1976; Cramp and Simmons 1977; Graubits and Janaus 1977; Moskalev 1977; Zhalakevicius 1977).

Importance of Simpson Lagoon to Molt Migrants. Some oldsquaws and smaller numbers of eiders and scoters land in Simpson Lagoon during their westward molt migrations (Table 8). However, the peak of the oldsquaw molt migration occurs in early July, around the time of breakup of the lagoon ice. In many years the amount of open water in the lagoons at the time of peak oldsquaw movement is low (shoreleads only). The very large numbers of male oldsquaws (tens of thousands) that molt in the lagoon do not reach their peak abundance until later in July, after breakup and the peak of westward molt migration (see 'MOLTING' section, below). Thus the lagoon is of only moderate importance to ducks during molt migration *per se*, but it is of great importance as a destination for molting oldsquaws.

Fall Migration

Brant, oldsquaws, phalaropes and, to a lesser degree, arctic terns are abundant late summer and fall transients in Simpson Lagoon. Loons and eiders are also common westbound migrants, but their numbers, like those of oldsquaws, are apparently small relative to numbers passing Point Barrow at this time (*cf.* Timson 1976). Most glaucous gulls, as well as many oldsquaws and eiders, probably migrate westward through the lagoon in late September and October, after our observations ended.

Waterbirds whose migration is concentrated along the coast are most susceptible to development of the nearshore zone. The brant appears to be the species whose autumn migration route through the Simpson Lagoon area is most narrowly confined to the coastal zone. Brant fly westward in a narrow corridor along the coast from the northern Yukon at least as far as Simpson Lagoon (see 'Results', above). They commonly land on coastal wetlands during these flights (Searing et al. 1975; Bergman et al. 1977; Koski 1977). Brant would be especially vulnerable if high water levels caused by a late summer storm (Henry 1975) carried oil onto low-lying coastal areas. The large flocks of brant that molt near Cape Halkett, west of Simpson Lagoon, during at least some summers (King 1970) might also be vulnerable.

The westward migration of brant through the south-central portion of the Beaufort Sea area is mainly WNW along the coast, but west of Simpson Lagoon most brant apparently follow a more direct westerly or WSW route overland south of Barrow (Johnson 1971; Pitelka 1974; Timson 1976). It is not surprising that brant, despite their close association with marine areas, undertake this overland flight. In spring, a considerable number of brant fly NE across interior Alaska (see Cade 1955 and earlier discussion). Furthermore, the normal migration routes of many brant in eastern North America and Europe include long overland segments (Lewis 1937; Bellrose 1976; Bergman 1978).

Oldsquaws migrated west through Simpson Lagoon in late summer of 1977, and tens of thousands still in the area when our observations ceased must have migrated away from Simpson Lagoon in late September or perhaps October. However, the amount of westward migration through the lagoon in late summer was modest compared to that at Point Barrow (*cf.* Timson 1976). Thus it is probable that many oldsquaws bypass the lagoon during fall migration. The Point Barrow radar has detected broad-front westward migration over the North Slope, coast, and southern Beaufort Sea in autumn (Flock 1973); this migration probably included many oldsquaws.

Eiders are even less conspicuous fall migrants along the arctic coast east of Point Barrow than are oldsquaws (Table 11). Molt and fall migration of eiders are not clearly distinguishable in northern Alaska; males move west mainly in July, but many females begin to move west toward molting areas in August. By early September young birds are also beginning to move west, along with later-migrating females (Johnson 1971; Timson 1976). In late summer and fall, as during the peak of the molt migration of males in July, westbound eiders are much less numerous at Simpson Lagoon and elsewhere along the south-central coast of the Beaufort Sea than at Point Barrow. Some eiders migrate west over the shallow marine waters seaward of the barrier islands, but few are seen far offshore in the Beaufort Sea during late summer (Bartels 1973; Frame 1973; Watson and Divoky 1974; Searing et al. 1975; Harrison 1977; Divoky 1978a). Thus the routes of most westbound eiders past the Simpson Lagoon area during the molt and fall migration periods are uncertain; but it is clear that most eiders do not land in Simpson Lagoon, or fly over the lagoon at low altitudes.

Glaucous gulls concentrate in the Simpson Lagoon area during mid September (Table 9), which is the time when their westward migration is beginning. Most of the birds then in the lagoon are feeding rather than actively migrating (see 'PREMIGRATORY STAGING' section, below). It is not certain what route these gulls follow during their subsequent departure from the lagoon. However, glaucous gulls are common offshore in the western Beaufort Sea in September (Watson and Divoky 1974; Divoky 1978a), so the fall migration is probably not confined to the coastal zone.

Arctic terns, like glaucous gulls, are common fall migrants along the barrier islands, but also occur offshore during the fall emigration (see Results).

Only very small numbers of Sabine's gulls and jaegers migrate west along the south-central coast of the Beaufort Sea in fall (see Results). Some jaegers may migrate westward over the interior of the arctic coastal plain or southward through the mountains, as in spring (Dean et al. 1976). However, these birds are common offshore in the Beaufort Sea during late summer (Frame 1973; Watson and Divoky 1974; Divoky 1978a), and it is probable that most westward emigration from the area is over offshore waters. Sabine's gulls appear to concentrate in the Point Barrow area before moving southwest through the Chukchi Sea.

Juvenile phalaropes (predominantly red but some northern) are abundant along shorelines in the Simpson Lagoon area during August, but then disappear. The adults have already departed by the time that juveniles concentrate along the lagoon shorelines. The departure routes of these phalaropes are not known. Very large numbers of red phalaropes occur near Point Barrow in August and early September (Connors and Risebrough 1977, 1978; Connors et al. 1979). Their marking studies suggest that there is much day-to-day turnover in the individuals present, especially after mid August. However, it is uncertain whether red phalaropes migrate from Simpson Lagoon WNW to Point Barrow in late summer.

In the Herschel Island-Nunaluk Spit area of the northern Yukon, thousands of northern phalaropes were observed moving predominantly eastward in August and early September of 1972 (Gollop and Davis 1974). However, Vermeer and Anweiler (1975) suggest without details that thousands of northern phalaropes moved west in that same area in August 1973. Northern phalaropes, at least, are known to migrate overland for long distances in western Canada (Godfrey 1966; Sadler and Myres 1976) and also in Europe (Hildén and Vuolanto 1976; Glutz et al. 1977). Thus it should not be assumed that all phalaropes migrate around the coast of Alaska.

Whistling swans, white-fronted geese, pintails and scoters are not conspicuous fall migrants near the coast in the Simpson Lagoon area. These birds are much more conspicuous in the northern Yukon and Mackenzie Delta area during late summer. There they are observed to migrate east and southeast (Table 11; see also Campbell 1973; Gollop and Davis 1974; Schweinsburg 1974a). Individuals that summer in northern Alaska must migrate either ESE along the coastal plain into the Yukon, or south through interior Alaska (see Irving 1960). They do not make significant use of the waters near Simpson Lagoon during this migration.

NESTING STUDIES

Results

The numbers, densities and fates of nests of the various bird species that were found nesting in the study area during 1977 and 1978 are presented in Tables 12-15. Fifty active nests were found on the barrier islands during 1977, representing a total density of 11.4 nests/km^2. Of these 50 nests, 38 (21.1 nests/km^2) were found on the Pingok Island tundra plots and on the tundra-covered portions of the other barrier islands; many of these nests (18 of 38, or 10.0 nests/km^2) were of lapland longspurs. The remaining 12 nests (9.24 nests/km^2) were found on the portions of the barrier islands, spits and bars that were comprised of gravel and sand.

During 1978, the complete study area was not censused for nesting birds. Only Plot 2 on Pingok Island was monitored as representative barrier island tundra habitat. On this plot six nests (20 nests/km^2) representing three species were found during 1978 compared with 11 nests (37 nests/km^2) representing two species during 1977. The average density of birds on this plot for the two year period of study was 28 nests/km^2, which is approximately half the density of birds (60 nests/km^2) found nesting on the comparative mainland tundra plot (Plot 3) established at Milne Point during 1978 (Table 14). Furthermore, the diversity of bird species nesting on the mainland tundra plot (10 species on the plot and an additional 7 species nearby) was more than three times greater than that on the Pingok Island tundra plot (three species during 1978 and two species during 1977; no additional species nested near the barrier island tundra plot during either year).

Based on the total number of nests found in the tundra-covered portions of the barrier islands in the study area, the overall density of all species of birds nesting in this type of habitat was 21.1 nests/km^2 during 1977 and 20.0 nests/km^2 during 1978; an overall value of 20.6 nests/km^2 for this habitat was calculated for the two year period of this study. Similarly, the numbers of territorial male (Π♂♂) birds recorded on tundra plots 1 and 2 on Pingok Island during 1977 were 24.0/km^2 and 20.0/km^2, respectively.

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Table 12. Active bird nests found during 1977 on the Jones Islands and on adjacent spits and bars in Simpson Lagoon, Alaska.

	Type of Nesting Habitat				Fate of Nest				
	Tundra (3.9 km^2)		Gravel/Sand (2.6 km^2)		Successful*				
Species	Nests (#)	Density (nests/km^2)	Nests (#)	Density (nests/km^2)	Nests (#)	Density (nests/km^2)	Predated	Deserted	Other/ Unknown
Lapland Longspur	18	10.00[†]	0	0.00**	7	3.89	8	0	3
Willow Ptarmigan	1	0.56	0	0.00	0	0.00	0	0	1
Snow Bunting	4	2.22	2	0.77	3	1.32	0	0	3
Oldsquaw	0	0.00	2	0.77	0	0.00	1	1	0
Dunlin	3	1.67	0	0.00	0	0.00	0	0	3
Ruddy Turnstone	1	0.56	0	0.00	0	0.00	0	0	1
Baird's Sandpiper	8	4.44	0	0.00	1	0.56	3	0	4
American Golden Plover	1	0.56	0	0.00	1	0.56	0	0	0
Parasitic Jaeger	1	0.56	0	0.00	1	0.56	0	0	0
Common Eider	0	0.00	2	0.77	0	0.00	1	1	0
King Eider	1	0.56	0	0.00	0	0.00	1	0	0
Arctic Tern	0	0.00	3	1.15	0	0.00	2	0	1
Glaucous Gull	0	0.00	3	1.15	2	0.77	0	0	1
Total	38	21.13	12	4.61	15	7.66	16	2	17

* A nest was judged to be successful if evidence (many times only circumstantial evidence) suggested that some young from the nest had fledged.

[†] Density calculations are based on the 1.8 km^2 of tundra area surveyed during nest searches.

**Density calculations are based on the 2.6 km^2 of gravel/sand area surveyed during nest searches.

Table 13. A comparison of bird densities on two tundra plots on Pingok Island and on the total area of tundra surveyed during nest searches on the Jones Islands, 1977*.

Species	Pingok Plot 1 (0.625 km² tundra)				Pingok Plot 2 (0.300 km² tundra)				Total Tundra Surveyed During Nest Searches (1.80 km²)	
	Nest Searches		Counts of Π ♂♂		Nest Searches		Counts of Π ♂♂			
	# Nests	Density	#Π ♂♂	Density	# Nests	Density	#Π ♂♂	Density	# Nests	Density
Lapland Longspur	6	9.60	14	22.40	8	26.67	6	20.00	18	10.00
Willow Ptarmigan	-	-	-	-	-	-	-	-	1	0.56
Snow Bunting	-	-	-	-	-	-	-	-	4	2.22
Dunlin	-	-	-	-	3	10.00	-	-	3	1.67
Ruddy Turnstone	1	1.60	-	-	-	-	-	-	1	0.56
Baird's Sandpiper	2	3.20	1	1.60	-	-	-	-	8	4.44
American Golden Plover	1	1.60	-	-		-	-	-	1	0.56
Parasitic Jaeger	1	1.60	-	-	-	-	-	-	1	0.56
King Eider	-	-	-	-	-	-	-	-	1	0.56
Total	11	17.60	15	24.00	11	36.67	6	20.00	38	21.13

*Counts of territorial males (Π ♂♂) were conducted only on Plots 1 and 2 on Pingok Island. All densities are per km².

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Table 14. A comparison of bird nest densities on a mainland tundra plot and a barrier island tundra plot in the Simpson Lagoon-Jones Islands area of Alaska (1977-1978).

	Pingok Plot 2 (0.300 km^2)						Milne Pt. Plot (0.250 km^2)		
	1977			1978			1978		
Species	#Nests	Density*	Fate[§]	#Nests	Density	Fate[§]	#Nests	Density	Fate[§]
Pintail	-	-		-	-		1	4.00	+
King Eider	-	-		-	-		1	4.00	+
Spectacled Eider	-	-		-	-		1	4.00	+
Baird's Sandpiper	-	-		-	-		2	8.00	+
Dunlin	3	10.00	-	2	6.67	+	1	4.00	+
Semipalmated Sandpiper	-	-		2	6.67	+	1	4.00	+
Buff-breasted Sandpiper	-	-		-	-		1	4.00	+
Pectoral Sandpiper	-	-		-	-		1	4.00	+
American Golden Plover	-	-		-	-		1	4.00	+
Lapland Longspur	8	26.67	5+	2	6.67	+	5	20.00	+
TOTAL	11	36.67		6	20.01		15[†]	60.00	

*All densities are per km^2.

[†] Within a linear distance of approximately 2.50 km E and 0.25 km S, W and N of the Milne Pt. tundra plot, an additional 18 nests were recorded. These included nests of the arctic (1) and red-throated (1) loon, white-fronted goose (1), king eider (2), spectacled eider (2), dunlin (1), oldsquaw (2), Sabine's gull (4), arctic tern (3) and snow bunting (1). No additional nests were either observed or suspected in areas similarly adjacent to the comparable tundra plot on Pingok Island. All densities are per km^2.

[§] During 1978, no evidence was found of predation or desertion of nests on mainland or barrier island tundra plots; apparently all of these nests were successful. During 1977 all three dunlin nests were destroyed by predators and three of the eight longspur nests were destroyed by predators.

Table 15. A comparison of the numbers of nests found on two gravel-covered barrier islands in the Jones Islands-Simpson Lagoon area of Alaska, 1976-1978. (Thetis Island data for 1976 provided by James W. Helmericks.)

	Species														
	Common Eider			Arctic Tern			Glaucous Gull			Brant			Total		
Island	1976	1977	1978	1976	1977	1978	1976	1977	1978	1976	1977	1978	1976	1977	1978
Spy Island*															
# Active Nests	4	0	4	-	2	5	3	0	4	-	0	0	7	2	13
# Nest Scrapes** or Inactive Nests	-	72	84	-	41	29	-	0	2	-	0	0	-	113	115
# Destroyed Nests	-	15	1[†]	-	-	-	-	8	0	-	0	0	-	23	1
Thetis Island*															
# Active Nests	38	-	34	1	-	2	4	-	5	3	-	9	42	-	50
# Nest Scrapes or Inactive Nests	-	-	198	-	-	8	-	-	4	-	-	1	-	-	211
# Destroyed Nests	-	-	0	-	-	-	-	-	0	-	-	0	-	-	0

*According to J.W. Helmericks (pers. comm., 1978) arctic foxes were present on Spy Island in 1976 as well as 1977, although Divoky (1978b) made no mention of foxes there during his visit in 1970; none were present during 1978. Arctic foxes have seldom been reported on Thetis Island in summer. Thetis Island was not intensively surveyed during 1977.

[†] A snowy owl killed a female common eider as she incubated a clutch of eggs on Spy Island. We recorded no other evidence of nest predation during 1978.

**Depressions in the gravel or sand designating an early stage of nest establishment.

No counts of territorial males were made during 1978 on either the barrier island or the mainland tundra plot.

Table 13 compares the species composition, numbers of nests and numbers of territorial males observed on the two census plots on Pingok Island during 1977; the total numbers of nests found in all tundra habitats throughout the study area are also shown.

No nests were found along the section of the mainland shoreline between Oliktok Point and Beechey Point during 1977; however, two active nests (one common eider nest and one glaucous gull nest) were found on the gravel/sand spit projecting west from Beechey Point, and at least two active glaucous gull nests were present on the Oliktok Point gravel bar. These bars are separated from the mainland by water and are comprised of sand and gravel substrates similar to those found on the barrier islands. This mainland shoreline was not surveyed for nesting birds during 1978.

Most nests were checked twice during the early summers of 1977 and 1978 in order to assess their fates (Tables 12 and 14). However, fates of some nests were identified by using circumstantial evidence of fledging of young, desertion of eggs or young by adults, or by evidence of predation on eggs or young. Fox predation accounted for a high proportion of nest failures on the Jones Islands, and especially on Spy Island, during 1977. Approximately eight arctic foxes (1.2 foxes/km^2) were present on the Jones Islands after the ice retreated in mid July during 1977. Their distribution in 1977 is shown below:

Island	Number of Foxes
Spy	2
Leavitt	1
Pingok	2
Bertoncini	1
Bodfish	1
Cottle	1

Foxes were observed searching for bird nests on the tundra on Pingok, Bertoncini and Bodfish islands throughout the summer of 1977. Fox tracks and scats were abundant around active and inactive nests in all suitable nesting habitats along beaches and on the gravel portions of Spy, Leavitt and Cottle islands during 1977.

Arctic foxes were recorded on only four occasions during the June through September 1978 period; all of these sightings were on the mainland tundra near the field camp at Milne Point (Fig. 1). No foxes nor fresh fox tracks were recorded on any of the barrier islands in the study area during 1978.

During both 1977 and 1978 Spy Island was included within the intensive study area. Two arctic foxes were present there throughout the summer of 1977 and as a consequence only two active nests (both of arctic terns) were found on this island during that year--both of these nests were destroyed by foxes (Table 15).

Thetis Island, which lies off the mouth of the Colville River and west of Spy Island (Fig. 1), historically has been without arctic foxes in summer. Although this island was not intensively surveyed during 1977, extensive nesting by at least four species of marine-associated birds was recorded there (J.W. Helmericks, pers. comm. 1977 and 1978). During 1978, when no arctic foxes were recorded on any of the gravel-sand barrier islands in the study area, the number of nests on Spy and Thetis islands were compared (Table 15). Bird production on Spy Island increased from two active nests (1.3 nests/km^2) of one species (arctic tern) during 1977, to 13 active nests (8.7 nests/km^2) of three species (arctic tern, glaucous gull, and common eider) during 1978. Many additional scrapes, inactive nests or destroyed nests were present in each year (Table 15). On Thetis Island, bird production remained high; in 1978, 54 nests (34 nests/km^2) and 207 scrapes of four species were recorded.

Discussion

The number of nests found by us on the Jones Islands during 1977 was larger than that reported by Divoky (1978b) for the same islands in 1976 and larger than that reported by Gavin (1976) for the same islands surveyed yearly for the six-year period 1970-1975. Plot 2 on Pingok Island was the only barrier island tundra location censused by us during 1978. The density of birds on that plot was lower in 1978 than in 1977 primarily because of the few lapland longspur nests found during 1978. However, the six nests found by us on Plot 2 in 1978 was equal to the greatest number of nests found by Gavin on the whole of Pingok Island during any of his six years of investigation there. Divoky (1978b) found no nests on Pingok Island during his search there in 1976.

None of the species of birds that nested or attempted to nest on the tundra portions of the Jones Islands are unique to barrier islands. Most of these tundra nesting species were nesting on our mainland tundra plot during 1978 (and on those of others, see Table 16), in most instances at densities much higher than on the tundra portions of the Jones Islands (see Tables 12, 14).

The total nesting densities (all species) of birds on various tundra portions of the Jones Islands (17.6 to 36.7 nests/km^2) were markedly lower than the density on the adjacent mainland tundra in 1978 (60.0 nests/km^2). In fact, the only tundra area in Arctic North America where the recorded densities of nests or nesting pairs of birds have been accurately determined to be lower than on the Jones Islands was a High Arctic site on Devon Island, N.W.T., Canada (2.0 nests/km^2; Pattie 1977). Table 16 gives a comparison of the density and nesting success of selected species of tundra nesting birds at several locations along the Beaufort Sea coast of Alaska. The values vary from 20.0 nests/km^2 on Pingok Island during 1978 to 167 territories/km^2 at Barrow during 1977. The density of nests (60.0 nests/km^2) on our mainland tundra plot at Milne Point during 1978 was most comparable to densities (51.0 and 59.2 nests/km^2) found by P. Martin (Univ. of Alaska, pers. comm., 1980) in similar habitat at Brownlow Point (approximately 160 km east of Simpson Lagoon) during 1979.

The contrast between densities of birds on the tundra-covered portions of the Jones Islands and mainland is interesting. These differences may be a result of factors such as (1) a reduced availability of food (terrestrial and aquatic invertebrates) on the islands, or (2) a difference in soil substrate and vegetation type and therefore of nesting habitat, or (3) increased predation on birds on barrier islands. Investigations of insect populations and plant communities were not within the scope of this

Table 16. A comparison of bird nesting density and nesting success of selected species in tundra habitats at several locations along the Beaufort Sea coast of Alaska.

	Species				
Location	Dunlin	Baird's Sandpiper	Lapland Longspur	Snow Bunting	All Species
Prudhoe Bay (Norton et al. 1975)					
Density (nests/km^2)	4.6	-	7.7	-	96.7
Success (%)*	50	-	60	-	62
Barrow (Norton 1973)					
Density (nests/km^2)	13.9	24.8	30.0	15.0	133.5
Success (%)*	72	39	63	80	65
Barrow (Myers et al. 1977)					
Density (Plot 1, Territories/km^2)	21.2	4.6	31.8	6.1	167.0
Density (Plot 2, Territories/km^2)	20.4	-	22.2	3.7	148.0
Brownlow Point (P. Martin, pers. comm. 1980)					
Density-Upland Plot (nests/km^2)	3.9	-	19.6	-	51.0
Density-Lowland Plot (nests/km^2)	-	-	11.1	-	59.2
Jones Islands (present study)					
Density-1977 (nests/km^2)	1.7	4.4	10.0	2.2	21.1
Success[†] (%)**	0	13	39	75	30
Pingok Island-Plot 2 (present study)					
Density-1977, 1978 (nests/km^2)	10.0, 6.7	-, -	26.7, 6.7	-, -	36.7, 20.0
Success-1977, 1978 (%)**	0, 100	-, -	63, 100	-, -	45, 100
Milne Point (present study)					
Density-1978 (nests/km^2)	4.0	8.0	20.0	-	60.0
Success-1978 (%)**	100	100	100	-	100

*Eggs hatched/eggs laid in that nest = %.

[†] A nest was judged to be successful if evidence suggested that some young from the nest had fledged.

**Nests with some young fledging/total nests of that species = %.

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study; therefore the first two factors remain largely uninvestigated. However, Cannon and Rawlinson (1978) have shown that barrier islands along the central Alaskan Beaufort Sea coast are mainland remnants that have become separated from the adjacent North Slope through processes of coastal tundra erosion. Through these processes, large coastal lakes have gradually become connected to the marine system; the resulting peninsulas and seaward margins have gradually become barrier islands and the coastal lakes have gradually become coastal estuaries. The soils, vegetation and associated terrestrial fauna on the tundra-covered portions of the barrier islands, therefore, have basically the same origins as the adjacent mainland tundra.

No doubt the influences of the arctic maritime climate (Leavitt and Kozo 1978; Kozo 1979; Kozo and Brown 1979) near the barrier islands have had subtle influences on the soil and vegetation of the barrier islands (e.g., increased salinity, infiltration of sand into the tundra vegetation, cold temperatures associated with the persistence of ice and cold water along the seaward coasts of the islands). These factors, in turn, will have affected soil invertebrates (Tipulidae) that are important as food for many tundra nesting birds (Holmes and Pitelka 1968; Kistchinski 1978; Seastedt and McLean 1979).

Predation by arctic foxes apparently accounted for most of the nesting failure and consequently for the low density of successful nests on the tundra portions of the Jones Islands during 1977. Foxes may have preyed more heavily on birds' eggs during 1977 than during the immediately preceeding years because of the marked decline in the lemming population along the central Beaufort Sea coast during the winter of 1976 and spring of 1977 (L. Eberhardt, pers. comm., 1977). Lemmings are a major prey item of arctic foxes in tundra habitats (Chesemore 1968). Although old lemming nests and skeletal material were found on the tundra on the Jones Islands, we caught no lemmings (nor any small mammals) during 960 trap-nights (25 snap-traps) on Pingok Island during the summer of 1977. Furthermore, during the summer of 1978 we caught no small mammals during 538 trap-nights on Pingok Island and none during 478 trap-nights on the mainland plot at Milne Point.

Certain species of birds nest on gravel portions of the barrier islands. The small number of nests of common eiders found during 1977 were all on gravel portions of the barrier islands. Gravel substrates are most common on Thetis, Spy, Leavitt and Cottle islands. Arctic foxes apparently preyed heavily on the eggs of eiders during 1977 and the number of active nests found in these habitats was small. However, the numbers of nest scrapes* and destroyed nests† found on the gravel barrier islands during 1977 suggested that in the absence of arctic foxes, a great potential existed for successful nesting by such species as the common eider (and the arctic tern). No arctic foxes were recorded on the gravel barrier islands in our study area during 1978 and, as hypothesized in 1977 (Johnson 1978), the number of common eider nests in that habitat greatly increased.

Divoky (1978b) has mentioned that factors such as (1) the proximity of a barrier island to the mouth of a major river system, and (2) the phenology of snow and ice melt around barrier islands during spring, may play important roles in determining the presence or absence of arctic foxes and the amount of avian production on nesting islands. Divoky suggested that arctic foxes may be effectively barred from barrier islands by an early discharge of river flood-water across the ice and around barrier islands and/or by early snow and ice melt and consequent moat formation around barrier islands. Bird production can be high, as on the Jones Islands during 1978, during years when foxes are barred access to barrier islands. However, such events are irregular and unpredictable along the Beaufort Sea coast and the breeding strategies of such birds as the common eider, glaucous gull and arctic tern have evolved accordingly (Larson 1960; Evans 1970).

In summary, barrier island tundra generally supports fewer species and much lower densities of nesting birds (approximately 20 nests/km^2 of two to five species during 1977 and 1978) than does mainland tundra (60 nests/km^2 of 10 species during 1978). Gravel/sand barrier islands similarly support few species of nesting birds; however, some species that do nest in this habitat seldom nest in other habitats (e.g., common eider). Although arctic foxes prey heavily on eggs of all birds nesting on barrier islands, species nesting on the gravel/sand islands, possibly because they are more conspicuous (generally large size and less nesting cover) appear most susceptible to fox predation.

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*Depressions in the gravel or sand which designate an early stage of nest establishment.

†Nests with down present and/or with missing eggs, broken eggs or egg shells present.

Nesting potential on the gravel/sand barrier islands is high, but may not be realized during years when arctic foxes have access to these islands and prey heavily on birds' eggs. During a year (1978) when arctic foxes were absent from the barrier islands, bird production on the gravel/sand islands increased markedly.

MOLTING*

Results

Oldsquaw Pre-Molt Period

Distribution and Abundance. Low densities of oldsquaws were present in all Simpson Lagoon habitats on 5 and 20 June 1977, on 23 June 1978, and on 22 June 1979 (Table 17). On these dates the highest density of oldsquaws recorded on any transect in the intensive study area was only 3.2 birds/km^2, and this transect was over tundra habitats south of Simpson Lagoon on 20 June 1977 (Transect 5; see Table 17).

The 5 July 1977 and 5 July 1978 aerial surveys were conducted just after (in 1977) and during (in 1978) the peak of the male oldsquaw molt migration through the intensive study area. The peak densities of oldsquaws in Simpson Lagoon during this survey in 1977 (26.2 birds/km^2) and in 1978 (160.4 birds/km^2) were recorded in the only significant areas of available open water: in the shoreleads along the southern margins of the barrier islands (Transect 2; see Table 17). During 1977, 1978 and 1979, the mid-lagoon area (Transect 3) remained ice-covered until after 5 July and it therefore supported very low densities of oldsquaws until after that date (Table 17). The nearshore marine habitat adjacent to Simpson Lagoon (Transect 1) was similarly covered with ice until after 5 July; however, densities of oldsquaws in this habitat remained relatively low throughout the pre-molt period, regardless of ice cover.

The overall density of oldsquaws (1.7/km^2; 109 birds seen) recorded on 5 July 1978 during surveys west of the Simpson Lagoon study area was low (Fig. 18) compared to the overall density recorded in Simpson Lagoon (62.2/km^2; 2482 birds). Furthermore, although the number of oldsquaws (2736) recorded during surveys east of Simpson Lagoon as far as Flaxman Island was approximately equal to the number recorded in Simpson Lagoon, the overall density of oldsquaws east of Simpson Lagoon on this date

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*Oldsquaws molt almost continuously from early spring to late fall (Salomonsen 1941; Palmer 1976). Our use of the term 'Molting' or 'Molt Period' refers to the period when the birds have lost their wing feathers and are flightless.

Table 17. Densities (birds/km^2)* of oldsquaws recorded in all habitats during aerial surveys of five transects in the Jones Islands-Simpson Lagoon area during summer 1977-79.

	Transect					Mean (unweighted)
	1	2	3	4	5	
1977[†]						
5 June	0.0	0.0	0.0	0.2	2.6	0.6
20 June	0.0	1.6	0.0	0.9	3.2	1.1
5 July	2.2	26.2	2.9	21.6	1.9	11.0
28/29 July	0.1	401.7	501.1	516.4	1.2	284.1
15 August	-	811.3	-	161.9	5.8	326.3
30 August	3.3	73.1	184.6	68.0	0.0	65.8
22 September	3.4	21.6	928.1	220.0	0.0	234.6
1978						
23 June	0.0	1.3	0.0	0.2	1.4	0.6
5 July	0.1	160.4	5.4	2.2	1.4	33.9
15 July	2.5	1344.8	39.0	70.8	0.2	291.5
25 July	17.7	284.7	73.0	19.1	0.0	78.9
5/6 August	0.2	324.7	62.5	6.4	0.0	78.8
15 August	0.0	994.2	7.3	0.0	0.0	200.4
25 August	50.2	337.4	33.3	0.8	2.0	84.7
5/6 September	20.2	150.2	12.3	0.1	0.1	36.6
15 September	193.3	47.0	29.6	7.1	0.0	55.4
23 September	1.6	9.9	231.8	138.5	0.0	76.4
1979						
22 June	0.0	2.5	0.0	0.2	0.6	0.7
28/29 July	4.2	520.5	132.6	31.2	8.6	139.4
31 Aug./1 Sept.	24.7	78.9	330.3	0.0	0.0	86.8
23 September	15.8	231.6	3.4	113.7	0.0	72.9

*All oldsquaws recorded as 'On-Transect' (<200 m of each side of the aircraft), regardless of the habitat with which they were associated, have been included in these density calculations.

[†] Densities for transects 2 and 4 in 1977 may be lower than those that may be calculated from numbers presented in Table 20. In Table 21 the proportion of the total area surveyed, which has been used in density calculations, includes only lagoon habitats, and birds used in density calculations include only those that were associated with lagoon rather than terrestrial habitats.

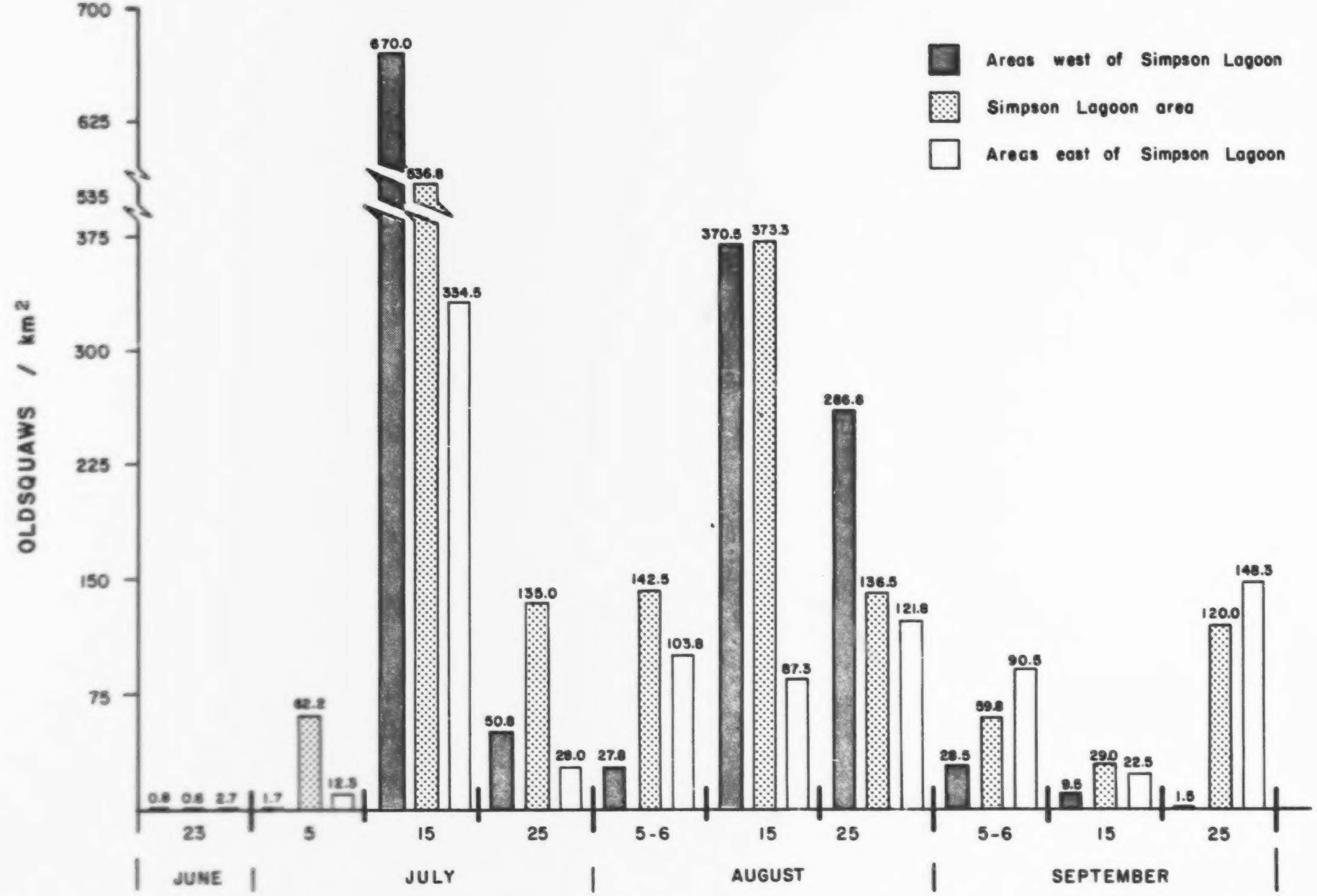

Figure 18. A comparison of the unweighted mean densities of oldsquaws in Barrier Island-Lagoon habitats to the east, west and in Simpson Lagoon, Alaska, June-September 1978.

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($12.3/km^2$) was considerably lower than that in Simpson Lagoon ($62.2/km^2$; Table 18, Fig. 18).

During the one aerial survey (22 June) conducted in the oldsquaw pre molt period of 1979, birds of this species were most densely concentrated at locations east of Simpson Lagoon (Fig. 19; Table 19).

Satellite imagery indicated that by 13 July 1977, by 6 July 1978 and by 14 July 1979, the ice had moved westward out of the coastal lagoon systems and that the ice seaward of the barrier islands had begun to break up along much of the Alaskan Beaufort Sea coast.

Oldsquaw Molt Period-Males

Distribution and Abundance. The aerial surveys conducted in mid to late July 1977-1979 indicated that the area seaward of the barrier islands continued to support low densities of oldsquaws after the ice had retreated from this area:

Date	Oldsquaws/km^2
29 July 1977	0.1
15 July 1978	2.5
25 July 1978	17.7
28 July 1979	4.2

Almost half of the birds recorded on 25 July 1978 were in two flocks (75 and 50 birds) near brash-ice and small ice pans seaward of Pingok Island.

During this same period, oldsquaws became much more abundant in the lagoon. The weighted average density of birds recorded in all habitats in Simpson Lagoon (Transects 2, 3 and 4) had increased from 6.0 birds/km^2 on the 5 July 1977 survey to at least 321.1 (and possibly 566.1) birds/km^2 on the 28-29 July 1977 aerial survey (Table 20), and from 15.5 birds/km^2 on 5 July 1978 to 183.2 birds/km^2 on 15 July 1978 (Table 21). The average density of oldsquaws recorded in lagoon habitats on a comparable date during the molt period in 1979 (28 July) was 145.0 birds/km^2 (Table 22). Between 15 July and 25 July 1978, however, the average density of oldsquaws recorded

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Table 18. Numbers of oldsquaws recorded on-transect along various sections of the Beaufort Sea coast in northeastern Alaska, 23 June to 23 September 1978.

Survey Date	West of Simpson Lagoon*		Simpson Lagoon		East of Simpson Lagoon[†]	
	# km^2 Surveyed	# Oldsquaws on-transect	# km^2 Surveyed	# Oldsquaws on-transect	# km^2 Surveyed	# Oldsquaws on-transect
23 June	12.0	10	39.9	22	31.3	85
5 July	65.5	109	39.9	2,482	222.8	2,736
15 July	12.0	8,013	39.9	21,423	31.3	10,463
25 July	65.5	3,326	39.9	5,384	162.0	4,552
5-6 August	65.5	1,813	39.9	5,608	315.1	32,661
15 August	12.0	4,431	39.9	14,903	31.3	2,731
25 August	5.5	1,583	39.9	5,444	126.9	15,445
5-6 August	65.5	1,862	39.9	2,388	315.1	28,543
15 September	12.0	112	39.9	1,156	31.3	705
23 September	12.0	17	39.9	4,792	126.9	18,819
All Dates	327.5	21,276**	399.2	63,682[††]	1393.9	116,740***
Mean Density		64.96		159.52		83.75

*This area included as many as six transects (163.7 km x 0.4 km = 65.5 km^2); it extended as far west as Atigaru Pt. and included most of the Colville River delta (see Figure 2A-8).

[†] This area included as many as 12 transects (787.8 km x 0.4 km = 315.1 km^2); it extended as far east as the Canada-U.S. border and as far north as the Midway Islands, north of Prudhoe Bay (see Figure 2C-6).

**Of the total 21,276 oldsquaws recorded on the 35 surveys of transects in areas west of Simpson Lagoon, 19,146 oldsquaws (90.0%) were recorded during the 10 surveys of one transect which included the south shoreline of Thetis Island.

[††] Of the total 63,682 oldsquaws recorded on the 30 surveys of transects in Simpson Lagoon, 54,428 oldsquaws (85.5%) were recorded during the 10 surveys of one transect along the south shoreline of the Jones Islands.

***Of the total 116,740 oldsquaws recorded on the 48 surveys of transects in areas east of Simpson Lagoon, complete data exist for 115,040. Of these, 87,559 oldsquaws (76.1%) were recorded during the 32 surveys of only four transects along the south shoreline of barrier islands.

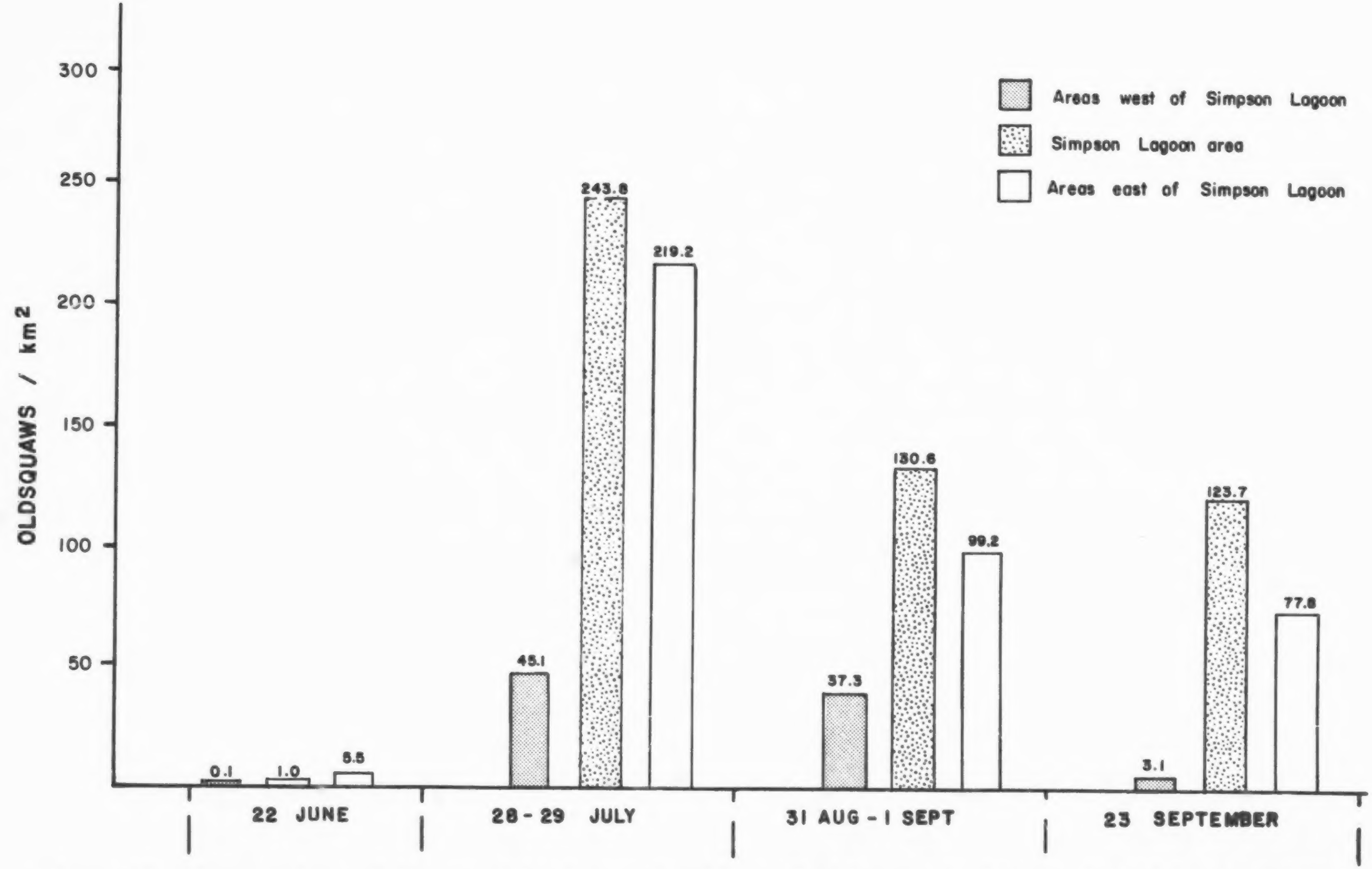

Figure 19. A comparison of the unweighted mean densities of oldsquaws in barrier island-lagoon habitats to the east, west and in Simpson Lagoon, Alaska, June-September 1979.

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Table 19. Numbers of oldsquaws recorded on-transect along various sections of the Beaufort Sea coast in northeastern Alaska, 22 June to 23 September 1979.

	West of Simpson Lagoon*		Simpson Lagoon		East of Simpson Lagoon†	
Survey Date	# km^2 Surveyed	# Oldsquaws on-transect	# km^2 Surveyed	# Oldsquaws on-transect	# km^2 Surveyed	# Oldsquaws on-transect
22 June	65.5	9	39.9	40	93.8	518
28 July	65.5	2,955	39.9	9,728	222.3	48,723
31 August	65.5	2,445	39.9	5,210	13.9	1,379
23 September	65.5	203	39.9	4,934	31.3	2,435
All Dates	262.0	5,612**	159.6	19,912††	316.3	53,055***
Mean Density		21.42		124.76		167.74

*This area included as many as six transects (163.7 km x 0.4 km = 265.5 km^2); it extended as far west as Atigaru Pt. and included most of the Colville River delta (see Figure 2A-B).

†This area included as many as 9 transects (555.8 x 4 km = 222.3 km^2); it extended as far east as the Canada-U.S. border and as far north as the Midway Islands, north of Prudhoe Bay (see Figure 2C-G).

**Of the total 5,612 oldsquaws recorded on the 24 surveys of transects in areas west of Simpson Lagoon, 3,350 oldsquaws (60%) were recorded during the 4 surveys of one transect which included the south shoreline of Thetis Island (Transect 6).

††Of the total 19,912 oldsquaws recorded on the 30 surveys of transects in Simpson Lagoon, 12,335 oldsquaws (62%) were recorded during the 4 surveys of one transect along the south shoreline of the Jones Islands (Transect 2).

***Of the total 53,052 oldsquaws recorded on the 19 surveys of transects in areas east of Simpson Lagoon, 51,435 oldsquaws (97%) were recorded during the eight surveys of only four transects along the south shoreline of barrier islands.

Table 20. Estimates of the total number of oldsquaws present in Simpson Lagoon during aerial surveys conducted in 1977.[†††]

Transect Number*	Location	Approximate Lagoon Area Represented (km^2)	Lagoon Area Surveyed (km^2)	5 June	20 June	5 July	28/29 July	15 August	30 August	22 September
2	Barrier Island-North Lagoon (<1.82 m deep)	22	7.77	0 (0)[†]	23 (23)	398 (398)	14,284 (5,045)	33,951 (11,991)	419 (148)	841 (297)
3	Mid-Lagoon (>1.82 m deep)	102	12.34	0 (0)	0 (0)	292 (35)	51,375 (6,165)	- (-)**	18,829 (2,271)	95,142 (11,417)
4	South Lagoon (<1.82 m deep)	36	9.66	0 (0)	11 (11)	269 (269)	24,921 (6,687)	7,800 (2,095)	2,687 (721)	10,617 (2,849)
Total		160	29.67	0 (0)	34 (34)	959 (702)	51,375 (6,165)[††]	41,759 (14,086)	21,935 (3,140)	106,600 (14,563)
Mean Density (weighted)				0.0	0.2	6.0	321.1***	(261.0)***	137.1	666.3

*Transect numbers 1 and 5 were seaward and landward, respectively, of Simpson Lagoon. Densities of oldsquaws on these transects were low (see Table 17) and estimates have not, therefore, been calculated for these transects.

[†] Numbers in parentheses represent the total number of oldsquaws recorded 'on-transect' (<200 m on either side of the aircraft) in lagoon habitats only.

**Incomplete survey; transects 1 and 3 were not surveyed on this date.

[††] Since the surveys of transects 2 and 4 were conducted on 28 July and that of transect 3 was conducted on 29 July, it is possible that some or all of the birds recorded on 28 July were also recorded on 29 July. We have, therefore, used the larger of the two estimates (the estimate from transect 3 rather than the sum of the values from transects 2 and 4), as a total for the survey.

***Minimum estimate.

[†††] During 1978, estimates of the total numbers of oldsquaws in Simpson Lagoon were calculated differently than they were in 1977. See Appendix IV for a discussion of these differences.

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Table 21. Estimates of the total number of oldsquaws present in Simpson Lagoon during aerial surveys conducted in 1978.[†]

Transect Number*	Location	Approximate Lagoon Area Represented (km²)	Lagoon Area Surveyed (km²)	23 June	5 July	15 July	25 July	5 August
2	North Lagoon (<1.82 m deep)	22	14.80	19 (19)	2,388 (2,388)	20,212 (20,026)	4,747 (4,239)	5,197 (4,836)
3	Mid-Lagoon (>1.82 m deep)	102	12.24	0 (0)	66 (66)	4,000 (480)	7,483 (898)	6,409 (769)
4	South Lagoon (<1.82 m deep)	36	12.88	3 (3)	28 (28)	5,092 (915)	539 (247)	462 (83)
Total		160	39.92	22 (22)	2,482 (2,482)	29,309 (21,421)	12,769 (5,384)	12,068 (5,688)
Mean Density (weighted)				0.1	15.5	183.2	79.8	75.4

continued...

Transect Number*	Location	Approximate Lagoon Area Represented (km²)	Lagoon Area Surveyed (km²)	15 August	25 August	5 September	15 September	23 September
2	North Lagoon (<1.82 m deep)	22	14.80	15,366 (14,913)	5,059 (5,024)	2,450 (2,236)	796 (700)	181 (147)
3	Mid-Lagoon (>1.82 m deep)	102	12.24	750 (90)	3,417 (410)	1,258 (151)	3,033 (364)	23,758 (2,851)
4	South Lagoon (>1.82 m deep)	36	12.88	0 (0)	28 (10)	5 (1)	381 (92)	7,937 (1,794)
Total		160	39.92	16,116 (14,303)	9,304 (5,444)	3,715 (2,388)	4,210 (1,156)	31,896 (4,792)
Mean Density (weighted)				100.7	58.2	23.2	26.3	199.2

*Transect numbers 1 and 5 were seaward and landward, respectively, of Simpson Lagoon. Densities of oldsquaws on these transects were low (see Table 17) and estimates have not, therefore, been calculated for these transects.

[†] During 1978, estimates of the total numbers of oldsquaws in Simpson Lagoon were calculated differently than they were in 1977. See Appendix IV for a discussion of these differences.

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Table 22. Estimates* of the total number of oldsquaws present in Simpson Lagoon during aerial surveys conducted in 1979**.

Transect Number	Location	Approximate Lagoon Area Represented (km²)	Lagoon Area Surveyed (km²)	22 June	28 July	31 August	23 September
2	North Lagoon (<1.82 m deep)	22	14.80	53 (37)	9,108 (7,703)	1,919 (1,167)	3,628 (3,428)
3	Mid-Lagoon (>1.82 m deep)	102	12.24	0 (0)	13,525 (1,623)	33,690 (4,043)	347 (42)
4	South Lagoon (<1.82 m deep)	36	12.88	7 (3)	559 (402)	0 (0)	4,092 (1,464)
Total		160	39.92	60 (40)	23,192 (9,728)	35,609 (5,210)	8,004 (4,934)
Mean Density (weighted)				0.4	145.0	222.6	50.0

*During 1979, estimates of the total numbers of oldsquaws in Simpson Lagoon were calculated differently than they were in 1977, but identical to those in 1978. See Appendix IV for a discussion of these differences.

**Transect numbers 1 and 5 were seaward and landward, respectively, of Simpson Lagoon. Densities of oldsquaws on these transects were low (see Table 17) and estimates have not, therefore, been calculated for these transects.

in lagoon habitats had decreased from 183.2 birds/km^2 to 79.8 birds/km^2; but this density remained substantially higher than the 15.5 birds/km^2 recorded several weeks earlier, on 5 July 1978. The density of 1344.8 birds/km^2 recorded on the 15 July 1978 survey of Transect 2 was the highest single-transect density of oldsquaws recorded during this study. On this date in 1978, about 20,026 oldsquaws were crowded along the south shoreline of the Jones Islands from Spy Island in the west to Cottle Island in the east. Most of these birds (99%, 19,827 birds, 2662.8 birds/km^2) were on the shoreline side of the aircraft (within 200 m of the shore). On 28 July 1979, 7703 oldsquaws were recorded along this same barrier island transect (Transect 2). Again most of these birds (approximately 81%, 6241 birds, 838.2 birds/km^2) were on the shoreline side of the aircraft.

Throughout the ice-free period of 1978 in Simpson Lagoon, significantly higher densities of oldsquaws were recorded on the barrier island shoreline transect (Transect 2) than on either the mid-lagoon transect (Transect 3) or mainland shoreline transect (Transect 4) (Friedman $\chi^2=10.34$, $n=8$, $k=3$, $P=0.003$). In fact, during the entire 1978 aerial survey program, a very large proportion (68%, 218,289 birds) of all oldsquaw sightings on surveys of all transects (from Thetis Island in the west to Demarcation Bay in the east) were during the surveys of six transects (Transects 2, 6, 12, 13-2, 14 and 15) located immediately south of barrier islands. Furthermore, most oldsquaws recorded on-transect on these six barrier island transects were seen on the shoreline side of the aircraft--within 200 m of shore (85.3% of 159,039 birds; Wilcoxon $z=3.86$; $n=30$ transect/date combinations; $P<0.001$).

This same phenomenon was generally evident during the three aerial surveys conducted during the open-water period in 1979; of 19,872 oldsquaws recorded in Simpson Lagoon during that period, 12,298 (62%) were along Transect 2, and of those, 80% (9845) were recorded along the shoreline side of the aircraft (within 200 m of shore). Of the total 101,509 oldsquaws recorded during all aerial surveys conducted in the summer of 1979, approximately 70% (70,801 individuals) were recorded along the same six barrier island transects mentioned above and about 84% (59,204 individuals) of those birds were recorded on the shoreline side of the aircraft.

By 15 July 1978, both the number and densities of oldsquaws had increased dramatically throughout the eastern Beaufort Sea coast of Alaska. However, even though dissimilar proportions of each area were surveyed, both the number and density of oldsquaws in Simpson Lagoon plus Harrison Bay (south of Thetis Island) were markedly higher than at locations farther east (Table 18; Fig. 18).

The raw densities of oldsquaws recorded on three Simpson Lagoon transects on 28-29 July 1977 were very similar--401.7, 501.1 and 516.4 birds/km^2 for transects 2, 3 and 4, respectively--but actual *densities of birds on the water* along transects 2 and 4 (which included some land) were somewhat higher. Nonetheless, the high density in mid-lagoon is noteworthy, and because of the similar densities on all lagoon transects, the estimates for 28-29 July 1977 in Table 20 are not very sensitive to the specific weighting procedure used. In contrast, on 25 July 1978 and 28 July 1979, the density of oldsquaws in lagoon habitats immediately south of the barrier islands (Transect 2) was markedly higher than in either the mid-lagoon area (Transect 3) or along the mainland shoreline (Transect 4).

	Oldsquaws/km^2		
Survey Date	Transect 2	Transect 3	Transect 4
25 July 1978	284.7	73.0	19.1
28 July 1979	520.5	132.6	31.2

The estimated peak number of oldsquaws present in Simpson Lagoon during the oldsquaw molt period was on the 28-29 July 1977 survey when at least 50,000 birds were estimated to be present--this was a substantial increase from the estimated total of 959 birds present during the preceding survey on 5 July 1977 (Table 20). Since no aerial surveys were conducted in areas east or west of the Simpson Lagoon study area during 1977, it is not known what proportion of the total number of oldsquaws present along the Beaufort Sea coast of Alaska during 1977 were molting in Simpson Lagoon.

No oldsquaws were systematically collected in Simpson Lagoon during the summer of 1979, so the peak of the molt period was not precisely determined. However, large numbers of apparently flightless oldsquaws (unable to fly away from the survey aircraft) were recorded along the coast of northeast Alaska during the 28-29 July survey (Table 22); we presumed, therefore, that the date of this survey was within the peak of the oldsquaw molt period. About 23,000 oldsquaws were present in Simpson Lagoon during this survey--quite similar to the estimated 21,000 oldsquaws molting in Simpson Lagoon during the peak of the molt in 1978 (see Table 21).

As mentioned earlier, even though dissimilar proportions of each area were surveyed (Table 21), the density of oldsquaws molting in Simpson Lagoon during 1978 was considerably higher than that in areas to the east and was slightly lower than that to the west in Harrison Bay (see Fig. 18). If all transects between Prudhoe Bay and Demarcation Bay had been surveyed during this period in 1978, however, the results of this comparison might have been quite different. For example, 20 of the 22 aerial survey transects (between Atigaru Pt. and Demarcation Bay) established during 1978 were resurveyed during 28-29 July 1979. The number of oldsquaws recorded on-transect in Harrison Bay on that date was 2955 (45.1 birds/km^2). However, the number recorded east of Simpson Lagoon (from Gwydyr Bay to Demarcation Bay) was almost 50,000 individuals, or 222.3 birds/km^2 (see Table 22). Thus, during the presumed peak of the oldsquaw molt period during 1979, about equal densities of oldsquaws were present in Simpson Lagoon and in similar barrier island-lagoon habitats to the east. However, the densities of oldsquaws in the Harrison Bay area, to the west of Simpson Lagoon, were much lower.

During the last two aerial surveys conducted in the oldsquaw molt period of 1978, on 25 July and 5 August, the estimated numbers of oldsquaws present in Simpson Lagoon (12,769 and 12,068 birds, respectively) were less than half those estimated to be present earlier, on 15 July 1978. On 25 July 1978, the densities of oldsquaws had declined not only in the Simpson Lagoon area, but also west of Simpson Lagoon as far as Atigaru Point and east of Simpson Lagoon as far as Flaxman Island (Fig. 18). During the extensive 5-6 August 1978 surveys, although the mean density of oldsquaws in Simpson Lagoon remained relatively unchanged from that during the 25 July survey, the mean density of oldsquaws had declined further in the area west of Simpson Lagoon. On the other hand, the number and mean density of oldsquaws east of Simpson Lagoon had increased substantially (Table 18, Fig. 18), no doubt due to the inclusion during this survey of the extensive barrier island-lagoon systems east of Flaxman Island as far as the U.S.-Canada border (see Fig. 2).

Oldsquaws were not evenly distributed within Simpson Lagoon during the molting period. On 28 July 1977, oldsquaws were most heavily concentrated at locations along the south sides of the barrier islands in Simpson Lagoon (Table 23). Fewer oldsquaws were recorded on this same date (28 July 1977) along the mainland shoreline of Simpson Lagoon and on 29 July at mid-lagoon locations (Table 23). Fewer oldsquaws molted in Simpson Lagoon during 1978 and 1979 than in 1977 (see Tables 20, 21, 22 and Fig. 20), and fewer major concentrations of oldsquaws were noted in Simpson Lagoon. However, concentrations that were recorded in 1978 were along the south shorelines of barrier islands, as in 1977 (Table 23).

At locations west and east of Simpson Lagoon during 1978 and 1979, major concentrations of molting oldsquaws were recorded primarily at barrier island locations (Table 24). West of Simpson Lagoon during both years, concentrations were recorded only at one location--south of Thetis Island. East of Simpson Lagoon during 1978, major concentrations were recorded south of Flaxman Island, south of the Jago-Tapaurak Spit, and south of Icy Reef. The largest concentrations found at mid-lagoon locations in 1978 were in Arey Lagoon, Jago Lagoon and Flaxman Lagoon (Table 24 and see Fig. 2). East of Simpson Lagoon during 1979, major concentrations of molting oldsquaws were recorded along the south shorelines of Long Island and Flaxman Island, along the south shore of Collinson Point, along the north shore of Oruktalik Lagoon and the north shore of Nuvagapak Lagoon (see Table 24). The only large concentration of molting oldsquaws found at a mid-lagoon location in 1979 was in Simpson Lagoon (see Table 23).

Sex Ratios and Body Condition. Based on the sex ratios of oldsquaws shot during the 29 July to 5 August 1977 and 1978 collection periods (Table 25; note that no oldsquaws were systematically collected during 1979), approximately 85% and 93%, respectively, of the oldsquaws present in the study area during this period were males. Several types of evidence

Table 23. Locations of major oldsquaw concentrations recorded during the period of summer molt in Simpson Lagoon, Alaska, 1977-79.

	# Oldsquaws
28 July 1977	
Barrier Island Shoreline Locations	
SE Shore Spy Island	3,100
S Shore Leavitt Island	3,065
SE Shore Cottle Island	5,200
	11,365
Mainland Shoreline Locations	
NW Shore Oliktok Pt.	2,700
SW Shore Milne Pt.	2,875
SW Shore Kavearak Pt.	1,225
	6,800
29 July 1977	
Mid-Lagoon Locations. Totals probably underestimated because of incomplete coverage.	
Between Beechey Pt.-E End Cottle Is.	1,750
Between Kavearak Pt.-Bertoncini Is.	4,575
	6,325
25 July 1978*	
Barrier Island Shoreline Locations	
SW of Spy Island	1,371
	1,371

...Continued

	# Oldsquaws
5 August 1978*	
Barrier Island Shoreline Locations	
SW of Spy Island	997
SW of Leavitt Island	1,000
SW of Pingok Island	1,022
S of Cottle Island	964
	3,983
28 July 1979	
Barrier Island Shoreline Locations	
SW Shore Spy Island	1,098
Between Spy Island-Leavitt Island	1,121
1 km W Fat Point, Pingok Island	926
2 km East of Pingok Island	2,655
SW Shore Cottle Island	996
	6,796
Mid-Lagoon Locations	
3 km SW Fat Point, Pingok Island	1,728
	1,728

*During aerial surveys conducted in 1978 no major oldsquaw concentrations were recorded along mainland shorelines or at mid-lagoon locations in Simpson Lagoon.

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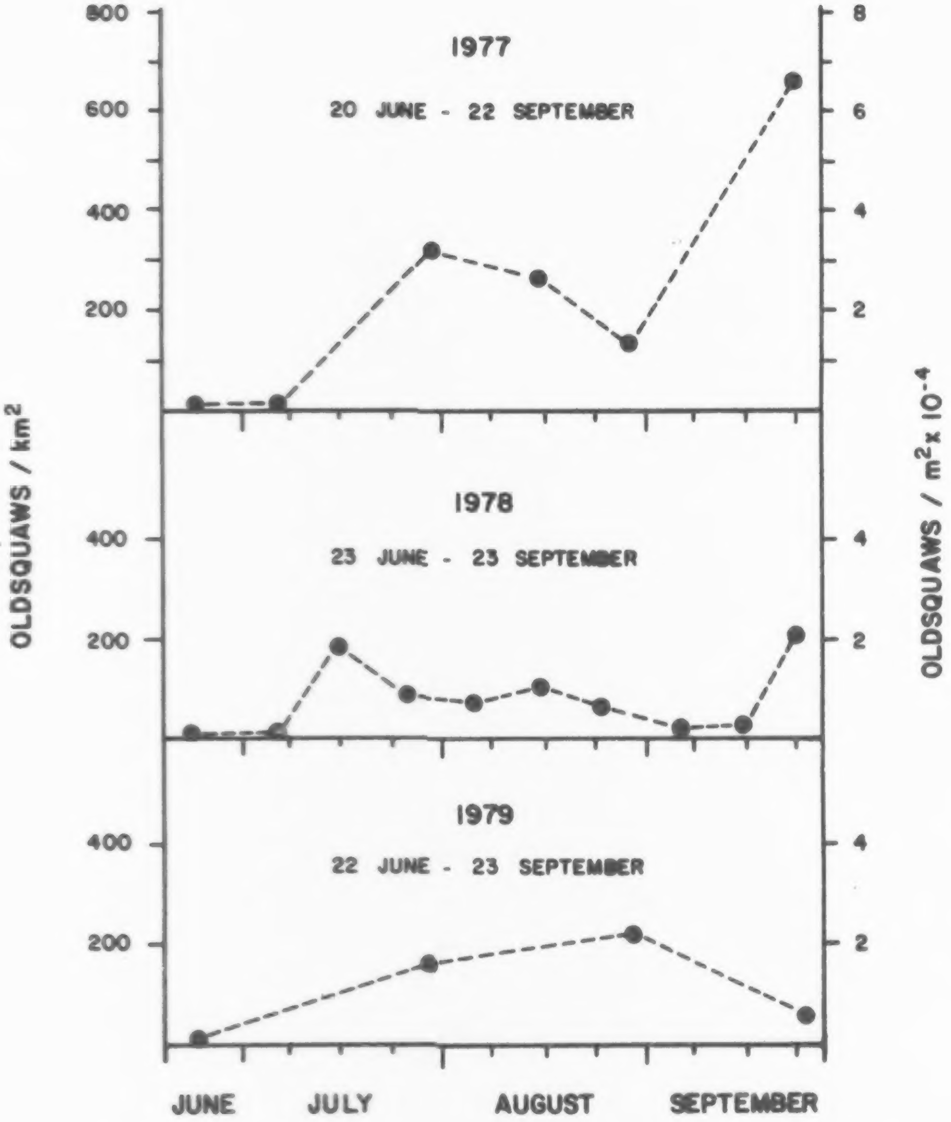

Figure 20. The change in the weighted mean density of oldsquaws (from Tables 21 and 22) throughout the seasons of 1977, 1978 and 1979 in Simpson Lagoon, Alaska.

Table 24. Locations of major oldsquaw concentrations recorded during the period of summer molt at Barrier Island-Lagoon locations along the Beaufort Sea coast of NE Alaska, 1978-79. This table includes some birds recorded off-transect.

	# Oldsquaws
28-29 July 1978	
Barrier Island Shoreline Locations	
S Shore Thetis Island	2,500
SW of Spy Island	1,371
SW Shore Long Island	2,644
	6,515
5 August 1978	
Barrier Island Shoreline Locations	
S Shore Thetis Island	1,275
S Shore Jones Islands (see Table 23)	3,983
SW Shore Long Island	3,844
SE Shore Long Island	1,262
S Shore Flaxman Island	5,835
SW Shore Arey Island	1,415
SE Shore Arey Island	2,625
S Shore Jago-Tapaurak Spits	5,932
S Shore Icy Reef	4,309
S Shore Demarcation Spit	1,550
	32,030
Mid-Lagoon Locations	
Arey Island	2,070
Jago Lagoon	1,660
Flaxman Lagoon	2,305
	6,035

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Page 2...

	# Oldsquaws
28-29 July 1979	
Barrier Island Shoreline Locations	
S Shore Thetis Island	1,770
S Shore Jones Islands (see Table 23)	6,796
SW Shroe Long Island	4,782
S Shore McClure Islands	2,425
S Shore Stockton Islands	2,477
S Shore Flaxman Island	5,543
NW Shore Canning Lagoon*	1,182
NE Shore Canning Lagoon	2,610
S Shore Collinson Point	5,510
b/t Collinson and Anderson Points	1,646
S Shore Anderson Point	1,315
S Shore Arey Island	2,013
N Shore Oruktalik Lagoon	4,039
N Shore Nuvagapak Lagoon	4,231
N Shore Demarcation Bay	3,954
	50,293

*This list includes the names of some waterbodies because some barrier islands and spits are unnamed.

Table 28. The change in adult oldsquaw wing length, weight and subcutaneous fat thickness during the pre molt, molt and post molt periods at Simpson Lagoon, Alaska (1977-1978). Values given are mean ± sd.

		Collection Intervals				
		17 June-27 July*	29 July-5 August	7-18 August	20-31 August	4-23 September
MALES		Pre Molt	Molt	Post Molt		
Wing Length (cm)	1977	23.1 ± 1.0 (n=13)	12.9 ± 2.0 (n=15)	19.3 ± 2.2 (n=10)	21.9 ± 1.1 (n=12)	22.8 ± 1.0 (n=7)
	1978	18.9 ± 5.1 (n=24)	14.2 ± 3.7 (n=14)	18.5 ± 1.5 (n=18)	19.1 ± 1.2 (n=13)	22.4 ± 1.4 (n=14)
Weight (g)	1977	869.3 ± 128.4 (n=13)	914.2 ± 64.7 (n=15)	879.0 ± 52.4 (n=10)	862.5 ± 72.1 (n=12)	949.3 ± 62.9 (n=7)
	1978	925.7 ± 71.2 (n=28)	920.8 ± 70.7 (n=14)	839.1 ± 49.5 (n=18)	853.9 ± 39.8 (n=13)	939.6 ± 85.7 (n=14)
SubQ Fat Thickness (mm)	1977	4.6 ± 0.9 (n=8)	5.6 ± 1.7 (n=10)	3.7 ± 1.5 (n=10)	3.2 ± 1.1 (n=12)	3.8 ± 1.7 (n=7)
	1978	4.7 ± 1.5 (n=28)	5.4 ± 1.2 (n=14)	3.6 ± 1.1 (n=18)	3.2 ± 0.8 (n=13)	3.5 ± 2.5 (n=14)
FEMALES		Pre Molt		Molt	Post Molt	
Wing Length (cm)	1977	22.3; 21.1 (n=2)	20.6; 22.2; 20.5 (n=3)	13.9 ± 1.7 (n=5)	17.2 ± 3.3 (n=6)	20.8 ± 0.4 (n=12)
	1978	-†	23.7 (n=1)	16.7 ± 7.5 (n=5)	16.6 ± 2.2 (n=7)	20.0 ± 1.8 (n=9)
Weight (g)	1977	653 ; 685 (n=2)	742 ; 699 ; 814 (n=3)	761.0 ± 88.8 (n=5)	737.0 ± 57.3 (n=5)	800.7 ± 62.9 (n=12)
	1978	-	675 (n=1)	745.0 ± 63.6 (n=5)	691.4 ± 61.2 (n=7)	775.6 ± 93.4 (n=9)
SubQ Fat Thickness (mm)	1977	heavy; light (n=2)	8.0; 3.0; 2.0 (n=3)	3.5 ± 1.6 (n=5)	3.9 ± 2.0 (n=5)	2.4 ± 1.0 (n=12)
	1978	-	3.0 (n=1)	4.0 ± 1.4 (n=5)	3.5 ± 1.0 (n=7)	3.0 ± 1.6 (n=9)
Sex Ratio** (F:M)	1977	1:6.5 (n=15)	1:5.0 (n=18)	1:2.0 (n=15)	1:2.4 (n=17)	1:0.6 (n=19)
	1978	0:28.0 (n=28)	1:14.0 (n=15)	1:3.6 (n=23)	1:1.9 (n=20)	1:1.6 (n=23)

*Five male and two female oldsquaws were accidentally caught in gill nets during the period 17 June to 27 June 1977 and one male oldsquaw was accidentally caught in a gill net on 28 June 1978. These eight birds were salvaged and have been included in the wing length and weight calculations. All other birds were adults collected during the period 11 to 27 July 1977 and 10 to 27 July 1978, respectively.

†No female oldsquaws were collected in this period in 1978.

**During the collection of birds no attempt was made to collect either males or females; hence, sex ratios are probably a true reflection of flock composition.

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indicated that the molt of male oldsquaws began in late July during 1977: the large proportion of males present then, the considerable interval since the peak of molt-migration, the fact that the peak number of birds was recorded in late July, and the abrupt decrease in the mean wing length of males from the 17 June-27 July collection period to the 29 July-5 August period (Table 25). Furthermore, the mean wing lengths of male oldsquaws collected during the 17 June to 27 July and the 29 July to 5 August periods were markedly (though not statistically) different (shorter during the early period and longer during the latter period) and more variable (Table 25; Fig. 21) than they were in 1977. Also, although the period of maximum subcutaneous fat thickness was similar during 1977 and 1978, oldsquaws attained maximum weight earlier during 1978 (within the 17 June to 27 July period) than during 1977 (29 July to 5 August period). These results suggest that during 1978 some male oldsquaws *began* to molt several weeks earlier than during 1977.

Although the weights of male oldsquaws collected in Simpson Lagoon did not change significantly during the summer of 1977, they did so during the summer of 1978; peak weight occurred during the late September period in 1978 (Table 26). During the summers of both 1977 and 1978 the thickness of the subcutaneous fat layer on the males did vary significantly with date, and was greatest (5.6 ± 1.7 cm during 1977 and 5.4 ± 1.2 cm during 1978; Table 25) in the 29 July-5 August collection period, during the latter part of the molt.

Table 27 gives information concerning the small samples of oldsquaws collected at inland tundra and barrier island locations during the summer of 1979.

Oldsquaw Molt Period-Females

Along the Alaskan Beaufort Sea coast, female oldsquaws usually incubate until mid to late July (Johnson et al. 1975). This explains the low number of females present in lagoon habitats or on mainland tundra lakes and ponds during the 17 June to 5 August period in both 1977 and 1978. Unexpectedly, in 1979 the highest density of oldsquaws (8.6 birds/km^2) recorded on the mainland tundra transect (Transect 5) during the three years of surveys was recorded during the 28 July survey. Few oldsquaws (0.6 birds/km^2) were

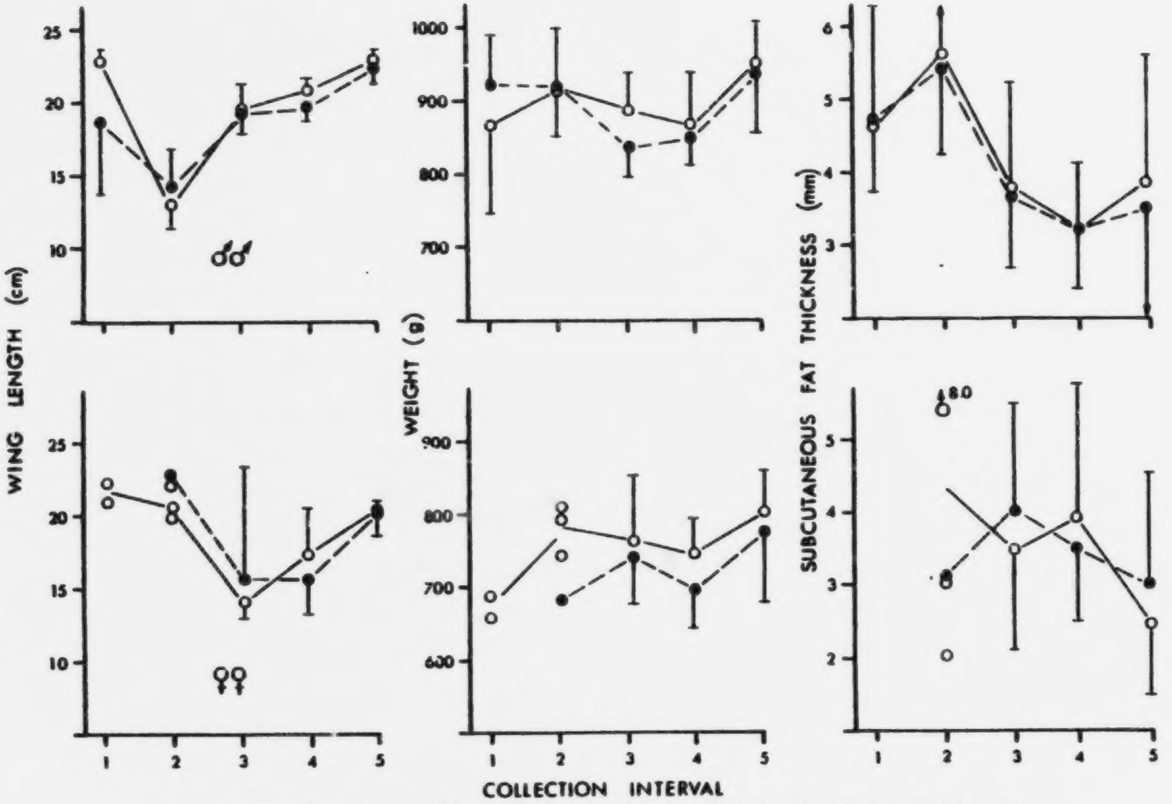

Figure 21. A comparison of the changes in wing length, body weight, and subcutaneous fat thickness of male and female oldsquaws during five collection periods in Simpson Lagoon during 1977 (○) and 1978 (●). (Collection intervals 1-5 correspond to dates presented in Table 25.)

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Table 26. Statistical comparisons of the change in adult male oldsquaw weights and subcutaneous fat thickness throughout the summers of 1977 and 1978.

	1977		1978	
Kruskal-Wallis One-way ANOVA	wt (g)	SubQ Fat Thickness (mm)	wt (g)	SubQ Fat Thickness (mm)
'H'	4.21	16.12	24.28	26.08
d.f.	4	4	4	4
N	57	51	86	86
P	>0.25	<0.005	<0.001	<0.001

Table 27. Body measurements of twelve oldsquaws collected at barrier island-lagoon and tundra locations during September 1979.

	Collection Location and Date		
	Tundra Lake	Barrier Island-Lagoon (Thetis Island)	
	1 September	2 September	23 September
Males			
Wing Length (cm)	25.0 (n=1)*	22.8 ± 0.54 (n=5)	-
10th Primary (cm)	11.3 (n=1)	14.3 ± 0.28 (n=5)	-
Weight (g)	-	-	-
Tarsus (cm)	4.5 (n=1)	4.6 ± 0.13 (n=4)	-
SubQ Fat Thickness (mm)	2.0 (n=1)	3.1 ± 0.57 (n=5)	-
Testes L x W (mm) Right	-	1.1 x 0.4 (n=5)	-
Left	-	1.1 x 0.4 (n=5)	-
Females			
Wing Length (cm)	18.2 ± 0.24 (n=5)**	-	21.7 (n=1)
10th Primary (cm)	9.6 ± 0.91 (n=5)	-	13.6 (n=1)
Weight (g)	-	-	795.0 (n=1)
Tarsus (cm)	4.3 ± 0.18	-	4.0 (n=1)
SubQ Fat Thickness (mm)	1.6 ± 0.41 (n=5)	-	2.0 (n=1)
Largest Ovum (mm)	-	-	2.0 (n=1)

*This immature male was collected from a brood of five accompanied by a flightless female.

**All five of these female oldsquaws were flightless and were collected from a flock of 75-80 flightless oldsquaws (mostly females) on a large tundra lake approximately 24 km inland from Simpson Lagoon.

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recorded during the earlier survey on 22 June 1979, and none were seen on the tundra transect during the final two surveys conducted on 31 August and 23 September.

During both 1977 and 1978, the ratio of female to male oldsquaws present in the study area was markedly higher during 7-18 August than it had been on 29 July-5 August (Table 25). This shift in the sex ratio was probably a result of an influx of female birds, apparently failed breeders, from inland tundra locations. The greatly reduced mean wing-lengths of females collected on 7-18 August of each year compared with values prior to this period (Table 25) indicated that the females collected then had very recently molted their flight feathers.

The larger and more variable wing lengths of the five female oldsquaws collected during the 7-18 August 1978 period compared with the wing-lengths of the five females collected during the same period in 1977 (Table 25) suggests that females as well as males initiated molt earlier in 1978 than in 1977.

Oldsquaw Post-Molt Period

Distribution and Abundance. Although female oldsquaws were molting during mid-August in 1977 and 1978, males had nearly completed replacement of their flight feathers by then (Table 25). The aerial survey conducted on 15 August 1977 was incomplete; overwater Transects 1 and 3 were not surveyed. However, high densities of oldsquaws were recorded on the two lagoon transects that were surveyed--811.3 birds/km^2 on Transect 2, and 161.9 birds/km^2 on Transect 4 (Table 17). During the 15 August 1978 survey, very few birds were recorded in habitats other than the shoreline transect south of the Jones Island, and the density of oldsquaws at this location was high (994.2 birds/km^2).

The estimated total number of oldsquaws present in the study area on 15 August 1977 (at least 41,759 birds) was smaller than the estimated total present during the previous survey of 28/29 July 1977 (at least 51,375 birds). However, had Transect 3 been surveyed on 15 August the total for this date would probably have been larger. The estimated total number of oldsquaws present in the study area on 15 August 1978 (16,116 birds) was slightly larger than the estimated number present during the preceding two surveys on 25 July and 5 August 1978 (12,769 and 12,068 birds respectively).

During both 1977 and 1978, a very large proportion of the oldsquaws present in Simpson Lagoon during the 15 August aerial survey were concentrated in waters immediately south of the Jones Islands (Tables 17 and 20-22). In fact, on 15 August 1978, 95.3% (15,366 birds) of the estimated total number of oldsquaws (16,116) present in the study area were recorded on the transect immediately south of the barrier islands (Transect 2).

The density of oldsquaws recorded on tundra habitats during the 15 August 1977 survey (5.81 birds/km^2) was noticeably higher than that recorded there during the preceding survey on 28 July 1977 (1.2 birds/km^2). This increase may be explained by the fact that female oldsquaws with broods would probably be more conspicuous on tundra ponds on 15 August than they were on 28 July (Bellrose 1976; King 1977). During 1978, oldsquaws were not detected on mainland tundra lakes and ponds until the 25 August survey (Table 17). In contrast to this, and as mentioned earlier, during 1979 no oldsquaws were recorded on the mainland tundra transect after 28 July.

By late August and early September of 1977, 1978 and 1979, although female oldsquaws were still flightless, most males had regained flight (mean wing length = 21.9 ± 1.1 cm during 1977, 19.1 ± 1.2 cm during 1978 and 22.8 ± 0.5 cm during 1979; Table 17 and 18a) and were capable of long-distance movements away from Simpson Lagoon. Possibly related to this, there was a marked decline from 15 to 30 August 1977 and from 15 August to 5 September 1978 in the number of oldsquaws observed in the study area (Tables 12 and 14). In contrast, during 1979 the peak in the estimated abundance of oldsquaws in Simpson Lagoon occurred during the late August (31 August) aerial survey. The estimated total number of birds in Simpson Lagoon (approximately 35,000 oldsquaws) was equivalent to a weighted mean density of 222.6 oldsquaws/km^2 (Table 22).

The largest concentration of oldsquaws recorded in Simpson Lagoon during the 30 August 1977 survey was of approximately 2775 individuals seen in the mid-lagoon area between Kavearak Point and Bertoncini Island. The only other large group of oldsquaws recorded in the study area on this date in 1977 was a concentration of 1800 birds SE of Oliktok Point.

The largest concentrations of oldsquaws seen in Simpson Lagoon during the 15 August to 5 September 1978 period were as follows:

Date	Location	No. Oldsquaws
15 August 1978	SW Spy Island	8296
	SE Spy Island	4085
	S Pingok Island	2910
25 August 1978	SW Leavitt Island	3526
5 September 1978	SW Cottle Island	1745

In 1978, approxiamtely 77% (4013 individuals, 330.3 birds/km^2) of the oldsquaws seen on-transect in Simpson Lagoon during the 31 August survey were at mid-lagoon locations. The largest concentration of oldsquaws seen (both on- and off-transect) on this date was 5800 birds swimming midway between Bodfish Island and Kavearak Point. Another large group of approximately 2500 individuals was seen off-transect swimming between Cottle Island and Beechey Point.

The sex ratios of oldsquaws collected during the 20-31 Augsut periods of both 1977 and 1978 remained in favor of males (71% and 66%, respectively). During 1977 and 1979, no oldsquaws were recorded on tundra habitats during the 30 August survey. During 1978, however, the density of oldsquaws on the tundra transect (Transect 5) increased from 0.0 birds/km^2 on 15 August to 2.0 birds/km^2 on 25 August and then declined to 0.1 birds/km^2 on 5 September 1978. Apparently some female and young oldsquaw had begun departing the tundra for coastal habitats after 25 August; juveniles were collected in Simpson Lagoon for the first time during the 25-31 August collection periods in 1977 and 1978.

The density of oldsquaws in offshore marine habitats seaward of the barrier islands on 30 August 1977 was still low (3.3 birds/km^2), compared with densities on lagoon habitats, and the few oldsquaws that were sighted on Transect 1 on this date were near ice pans and chunks of ice that had drifted landward from the pack ice, which was located farther offshore. During the comparable survey in offshore marine habitat on 25 August 1978, approximately 1800 oldsquaws (50.2 birds/km^2) were recorded on-transect among the many loose and scattered ice pans present off the coast of the Jones Islands. On this date the edge of the Beaufort Sea pack ice was only about 10 km offshore from the barrier islands. During the survey of this same nearshore marine transect (Transect 1) on 5 September 1978, approximately 850 oldsquaws (20.2 birds/km^2) were recorded in these waters, which were then ice-free. On 31 August 1979, 500 oldsquaws (350 on-transect, 24.7 birds/km^2; 150 off-transect) were recorded during the survey of Transect 1, seaward of the Jones Islands. The birds were gathered into three large flocks that appeared to be feeding among ice pans.

During the 22 September 1977 aerial survey, the weighted average density of oldsquaws recorded on the three Simpson Lagoon transects was 666.8 birds/km^2, a substantial increase from the average value of 137.1 birds/km^2 recorded on these same three transects during the previous survey on 30 August (Table 20). The density of oldsquaws recorded on Transect 3, in the mid-lagoon portion of the study area, was about 930 birds/km^2--the highest transect density of this species recorded during 1977. The estimated total number of oldsquaws present in the study area during the 22 September 1977 aerial survey was 106,600 birds (Table 20). Approximately 90% of these birds (95,142) were estimated to be present in mid-lagoon waters. No major concentrations of oldsquaws were observed along the southern margin of the barrier islands on 22 September. Over 90% (19,183 of 21,068) of all oldsquaws actually observed in the mid-lagoon area (including off-transect sightings) on 22 September were in the eastern half of the study area--east of a line from Jones Mound on the mainland to the survey marker at mid-Pingok Island. The largest concentration of oldsquaws observed during the 22 September 1977 survey (4082 oldsquaws) was in the mid-lagoon region between Kavearak Point and the west end of Cottle Island. Other major concentrations of oldsquaws were seen in mid-lagoon waters between Milne Point and Shacklo Point on Pingok Island (approximately 3000 oldsquaws) and in mid-lagoon waters between Milne Point and the survey marker at mid-Pingok Island (approximately 3000 birds).

Of the 8585 oldsquaws seen along the mainland shoreline of Simpson Lagoon on 22 September 1977, 95% (8009) were observed in the eastern portion of the study area. Major concentrations along the mainland on- and off-transect during 23 September 1978 were in the western half of the lagoon, i.e., west of a line from Milne Point to the survey marker at mid-Pingok Island. The only large concentration of oldsquaws recorded in Simpson Lagoon during this final survey was 4013 birds seen on- and off-transect in the large bay SW of Milne Point.

No major peak of oldsquaw abundance in Simpson Lagoon was detected during the late September survey in 1979. The weighted mean density of 50.0 birds/km^2 was considerably lower than the values of 199.2 and 666.3 birds/km^2 calculated for the surveys conducted on 23 and 22 September 1978 and 1977, respectively. Of the total 5521 oldsquaws recorded on- and off-transect in Simpson Lagoon on 23 September 1979, 62% (3428) and 33% (1795) were seen along the shorelines of the barrier islands and the mainland, respectively. Only 1.3% (75 birds) were seen at mid-lagoon locations; 4% (224 birds) were seen seaward of the barrier islands along the nearshore marine transect.

On 24 September 1979, while we were en route between the Colville Delta and Prudhoe Bay, we saw two very large concentrations of oldsquaws. Approximately 10,000 individuals were seen in the rough water (winds at 56 km/h from 225°) along the leeward (west) side of the bay west of Point McIntyre. Another large concentration of approximately 1000 oldsquaws was seen on a large lake approximately 24 km west of Prudhoe Bay.

Tables 28 and 29 give locations of major oldsquaw concentrations recorded during 1978 and 1979 periods of post molt in barrier island-lagoon habitats along the entire Beaufort Sea coast of NE Alaska. The extensive surveys conducted on 5-6 September 1978 indicated that very large concentrations of oldsquaws (approximately 8058 birds seen) were present in the barrier island-lagoon systems ESE of Brownlow Point. Slightly west of this location, in the lagoon area behind Flaxman Island, the single largest concentration of oldsquaws directly observed during the 3-year study (approximately 32,000 birds) was recorded. Similar large concentrations of oldsquaws in barrier island-lagoon habitats east of Prudhoe Bay as far as Flaxman Island were recorded during the final aerial survey on 23 September 1978 (Table 28). Poor weather during the 31 August-1 September and 23 September 1979 periods prevented surveys east of the Prudhoe Bay area consequently few post molting concentrations of oldsquaws were recorded at locations other than the Simpson Lagoon area.

Table 28. Locations of major oldsquaw concentrations* recorded during the post molt period (15 August to 23 September) at barrier island-lagoon locations along the NE coast of Alaska during 1978.

	# Oldsquaws
15 August	
Harrison Bay between Thetis Is. and Oliktok Pt.	3,245
SE Shoreline of Long Island	1,927
	5,172
25 August	
S Shoreline Thetis Island	1,022
SW Shoreline Long Island	2,347
S Shoreline Egg Island	2,315
S Shoreline Pole Island	1,479
S Shoreline Flaxman Island	6,111
	13,274
5-6 September	
Harrison Bay between Thetis Is. and Oliktok Pt.	1,335
S Shoreline Flaxman Island	5,603
ESE Brownlow Pt. (Canning Lagoon)	8,058
SE Konganevik Pt.	3,055
S Shoreline Icy Reef	1,212
Flaxman Lagoon	32,027
	51,290
23 September	
8 km N Heald Pt.	1,859
S Shoreline Narwhal Island	1,197
S Shoreline Pole Island	18,073
Flaxman Lagoon	7,338
Mikklesen Bay	5,009
Foggy Island Bay	4,717
N Howe Island	1,500
Gwydyr Bay	3,651
	43,344

*This table includes birds recorded both on- and off-transect. Concentrations in the Simpson Lagoon study area are described in the text.

Table 29. Locations of major oldsquaw concentrations* recorded during the post molt period (31 August and 23 September 1979) at barrier island-lagoon locations along the NE coast of Alaska during 1979.

	# Oldsquaws
31 August	
SW Shore of Long Island	1,343
	1,343
23 September	
Harrison Bay, approximately 6 km SSW of Atigaru Pt.	1,925
Prudhoe Bay, approximately 5 km WSW of Heald Pt.	1,380
	3,305

*This table includes birds recorded both on- and off-transect. Information regarding concentrations of birds recorded during post molt period in the Simpson Lagoon study area is mentioned in the text.

By 23 September of 1977 and 1978 both sexes of adult oldsquaws as well as juvenile birds were capable of flight; of the 12 and 9 female oldsquaws collected during the 4-23 September 1977 and 1978 collection periods (Table 25), four and one, respectively, were juveniles. Also noteworthy is the fact that the sex ratio of adult oldsquaws collected in the lagoon during the 4 to 23 September period had shifted in favor of females, especially during 1977 (female/male ratio=0.42 and 0.52 during 20-31 August 1977 and 1978, respectively; 1.67 and 0.62 during 4-23 September 1977 and 1978, respectively).

The weights of oldsquaws collected throughout the 1977 and 1978 seasons indicate that both males and females were very heavy during the September collection period. Surprisingly, the subcutaneous fat layer of both male and female oldsquaws tended to be thinnest during this same mid-September collection period (Fig. 21 and Table 25).

In summary, fewer male oldsquaws molted in Simpson Lagoon during 1978 than in 1977 and the molt for some males began up to two weeks earlier during 1978. Both of these factors may be related to an early spring break-up in 1978 and early flushing of ice not only from Simpson Lagoon but from the entire northeast coast of Alaska. During 1978 oldsquaws concentrated in very high densities immediately south of the Jones Islands during July, August and early September. During extensive coastal surveys in 1978 and 1979, concentrations of oldsquaws were recorded south of most barrier islands along the entire NE coast of Alaska from Thetis Island in the west to the Alaska-Canada border in the east. Male oldsquaws were generally fattest and heaviest during the peak of the molt in both 1977 and 1978.

After the period of molt by males in both 1977 and 1978, the numbers and densities of oldsquaws in Simpson Lagoon declined and remained low until late September. At this time, large numbers of female and newly fledged young oldsquaws arrived in Simpson Lagoon. Observations of large numbers of oldsquaws at locations east of Simpson Lagoon during surveys conducted in early and mid-September 1978 suggested that some of these late-arriving oldsquaws in Simpson Lagoon may have come from mainland tundra ponds and lakes that typically freeze over during late September, and from areas to the east. During the late September peak of abundance, oldsquaws were concentrated primarily at mid-lagoon locations.

During the 1978 season as a whole, the density of oldsquaws in Simpson Lagoon was not significantly different from densities recorded in areas to the west (in Harrison Bay) nor from densities recorded to the east (as far as the U.S.-Canada border) (Friedman $\chi^2=2.6$, n=10, k=3, P>0.35). On the other hand, during the summer of 1979, the densities of oldsquaws recorded in Simpson Lagoon and in the lagoons to the east were significantly higher than the density in the Harrison Bay area (Friedman $\chi^2=6.5$, n=4, k=3, P=0.042).

The aerial survey program during 1979 was less intensive than that during either 1977 or 1978. Based on the four surveys that were conducted in 1979, the seasonal trend in oldsquaw abundance in Simpson Lagoon during 1979 was different from that in either 1977 or 1978. Although densities of oldsquaws recorded in the study area on 22 June 1979 were comparable to those at that time in 1977 and 1978, those during late July 1979 (the presumed peak of the male molt period) were considerably lower than during 1977 and were slightly higher than during the same period in 1978. The peak density of oldsquaws in Simpson Lagoon during 1979 was in late August; during 1977 and 1978, late August through early September was typically a period of declining or low oldsquaw abundance in Simpson Lagoon. No dramatic increase in numbers of females and young-of-the-year in the lagoon was recorded during late September of 1979, as had occurred during both 1977 and 1978. Unseasonably warm weather prevailed along portions of the Alaskan North Slope during late September 1979; consequently large amounts of open water at tundra locations were available to oldsquaws and other water-associated birds at that time. Thus during late September 1979, many females and young-of-the-year oldsquaws may have not yet moved from tundra wetlands to coastal lagoons.

Discussion

Pre-Molt Period

In early June, during the peak of spring bird migration along the Alaskan Beaufort Sea coast, most rivers and streams begin to discharge massive volumes of water from the rapid snowmelt and runoff at interior tundra locations (Maykut and Church 1973:623). The river discharge flows out over the surface of the largely frozen lagoons to depths of nearly a meter at certain locations. Migrating water birds (loons and waterfowl) were observed landing and swimming on this melt-water during spring 1977 (see 'MIGRATION' section, this chapter).

The melt water eventually flows down through pressure cracks and strudel holes, and under the lagoon ice. The total duration of the spring flood is generally less than two weeks and it culminates when the ice lifts from the bottoms of the lagoons. After the lagoon ice has lifted (in mid to late June), anadromous fish and some species of invertebrates (primarily mysids) move from marine areas into the lagoon waters. At this time the lagoons provide limited feeding habitat for various species of birds, including arctic terns, several species of gulls, and post-breeding male oldsquaws. These birds are most commonly observed resting and feeding at locations near river mouths, along shore leads, and in the cracks and holes in the lagoon ice.

The floating lagoon ice gradually thins, breaks apart and floats westward (under the influence of the prevailing strong northeasterly winds; Kozo 1979) out of the lagoons. Most coastal lagoons are generally free of ice by mid to late July--two to four weeks earlier than marine areas north of the barrier islands. The exact time in July that the lagoons clear of ice depends on the thickness of the ice, the spring weather conditions and the configuration of the lagoon or bay. As the lagoons begin to clear of ice, post-breeding male (and to a lesser extent, non-breeding female) oldsquaws begin to concentrate in flocks in the shoreleads, and in the cracks and holes in the lagoon ice.

The oldsquaw is one of the most abundant species of waterfowl in the Beaufort Sea area (Barry 1974). Barry (1974) speculated that during spring migration in 1972, over 1.1 million oldsquaws moved into the southeastern portion of the Beaufort Sea.

Bellrose (1976) stated that oldsquaws are dispersed over the Arctic tundra to a greater extent than any other species of waterfowl. Hanson et al. (1956) found a pair of oldsquaws on each tundra pond that they investigated near the Perry River in Canada. Near Chesterfield Inlet, Canada, Höhn (1968) reported a pair of oldsquaws on almost every pond, even on those as small as 0.27 ha. Oldsquaws were the most common nesting species of duck on lakes along the Yukon North Slope during 1972 and 1973 (Gollop and Davis 1974; Sharp et al. 1974). Densities of oldsquaws on the Alaskan North Slope during the breeding season are also high (Bergman et al. 1977; Derksen et al. 1977; King 1977) relative to other waterfowl.

Surveys of summer populations of oldsquaws in Alaska (King and Lensink 1971) have led to the very conservative estimate of 125,000 present on the Arctic Slope (0.5 birds/km^2). Similarly, both Kistchinski (1976) and Krechmar et al. (1978) found the oldsquaw to be the most abundant species of waterfowl on the coastal tundra of northeast Siberia.

After the breeding season, large numbers of male and non-breeding female oldsquaws move from their breeding grounds and travel along traditional routes to specific locations where they continue their summer-long molt (see Salomonsen 1968, for a description of the molt-migration). Salomonsen (1968) argued that the potential shortage of food on the breeding grounds may be the ultimate cause of the molt migration in many species of waterfowl. As Taylor (1980) has summarized, the molt migration is typically regular and, although the evolutionary development of the molt-migration is not clearly understood, it apparently maximizes individual fitness and has significant survival value (Fredrickson and Drobney 1978).

Along the Alaskan North Slope, oldsquaws move from their breeding locations on the above mentioned lakes and ponds to nearshore coastal waters to feed and to molt (Johnson et al. 1975; Bellrose 1976; Palmer 1976).

Molt Period

The period of molt by male (and to a lesser extent by non-breeding female) oldsquaws along the Beaufort coast is generally between 15 July and 15 August. Prior to this period, as mentioned above, densities of oldsquaws in coastal habitats are highest in the only open water habitat available to them--at river mouths, in shoreleads around the margins of the barrier islands, in the shoreleads along the mainland shoreline, and to a lesser extent, in the cracks in the lagoon ice. During 1977, the peak of the oldsquaw molt occurred during the period 29 July to 8 August; during 1978, the peak was less distinct and the molt in Simpson Lagoon apparently occurred over a longer period. In 1978 the molt began possibly as early as 15 July in some birds. During both 1978 and 1979, the peak of molt by oldsquaws occurred roughly between 29 July and 5 August; in 1978 some birds were still incapable of flight in mid-August.

Several other investigators have documented the use of lagoons and bays along the Beaufort Sea coast by molting oldsquaws (Brooks 1915; Bartonek 1969; Bartels 1973; Schmidt 1973; Hall 1975; Ward and Sharp 1974; Gollop, Black et al. 1974; Gollop and Richardson 1974; Vermeer and Anweiler 1975; Barry 1976; Divoky 1978a).

Feather molt by birds is a costly physiological process (Payne 1972: 139-145). The energy requirements of molting birds increase because of increased metabolic costs for thermoregulation when feather loss reduces body insulation, and because of metabolic demands for feather replacement. Unlike most birds (and all other waterfowl), oldsquaws acquire three distinct plumages--they molt virtually continuously from early spring through late fall (Salomonsen 1941; Palmer 1976). The energetic costs of molt by oldsquaws, therefore, are probably considerably greater than for other waterfowl. In view of these facts, it is significant that in Simpson Lagoon, the thickness of the subcutaneous fat layer in male oldsquaws was greatest during the period of molt when insulation afforded by feathers was reduced. The subsequent decrease in the thickness of this fat layer after the peak of the molt probably was a result of the prior increased metabolic demands during molt.

Earlier we suggested that the availability of shelter and a reliable food supply prior to and during the molt period may be an important factor in increasing or maintaining adequate fat reserves during the molt (Johnson 1978).

Although the effects of wind on the energy requirements of molting seaducks have not been specifically investigated, the metabolic responses of other species to wind have been discussed by Stevens and Moen (1970), Gessaman (1973), Evans and Moen (1975) and Kelty and Lustick (1977). In general, the metabolic rate of a bird exposed to wind increases in proportion to the square root of wind speed. During 1977 we found no consistent quantitative evidence that oldsquaws sought shelter from the wind behind the barrier islands (Table 30). However, over half of all the oldsquaws observed during aerial and ground surveys during 1977 appeared to be associated with the lee sides of the barrier islands. During 1978, the relationship between the distribution of oldsquaws and the lee sides of the barrier islands was more clearly shown (Table 31). Approximately

Table 30. Distribution and abundance of oldsquaws in Simpson Lagoon in relation to wind, 1977.

Survey Date	Survey Type	Wind		Position of Oldsquaws						Total
				Lee Side of Islands		Mid Lagoon		Mainland Coast		
		Direction (°)	Speed (km/h)	#	%	#	%	#	%	
5 July	Aerial	Calm	Calm	398*	56.7	35	5.0	269	38.3	702
28 July†	Aerial	120	8	5,345*	44.4	-	-	6,687	55.6	12,032
1 August**	Ground	090	24	4,583	46.1	-	-	5,347	53.8	9,930
14 August**	Ground	060	16	19,938	87.8	-	-	2,758	12.2	22,696
15 August†	Aerial	135	8	11,991*	85.1	-	-	2,095	14.9	14,086
30 August	Aerial	090	5	148*	4.7	2,271	72.3	721	23.0	3,140
22 September	Aerial	270	27	297*	2.0	11,417	78.4	2,849	19.6	14,563
				42,700	55.3	13,723	17.8	20,726	26.9	77,149

*Total birds seen on and off transect.

†Because of logistic difficulties, the middle portion of the lagoon was not surveyed on 28 July or 15 August.

**During counts of oldsquaws from positions on the ground (1 and 14 August), the lagoon was divided only into north and south portions.

Table 31 . Distribution and abundance of oldsquaws in Simpson Lagoon in relation to wind, 1978.

Survey Date*	Wind		Position of Oldsquaws						
			Lee Side of Islands		Mid Lagoon		Mainland Coast		
	Direction (°)	Speed (km/h)	#[†]	%	#	%	#	%	Total
5 July	070	17.7	4,906	92.0	398	7.5	28	0.5	5,332
15 July	050	21.3	21,102	90.9	735	3.2	1,367	5.9	23,204
25 July	040	14.2	5,042	75.2	1,415	21.1	247	3.7	6,704
5 August	360	2.3	5,161	84.8	824	13.5	98	1.6	6,083
15 August	050	17.7	16,520	97.3	390	2.3	75	0.4	16,985
25 August	290	15.9	5,088	85.3	669	11.2	211	3.5	5,968
5 September	070	7.1	2,274	89.1	201	7.9	78	3.1	2,553
15 September	270	8.0	854	61.8	432	31.3	95	6.9	1,381
23 September	210	16.1	163	2.3	3,562	49.5	3,472	48.2	7,197
			61,110	81.0	8,626	11.4	5,671	7.5	75,407

*Aerial surveys.

[†] Total birds seen on and off transect.

90% of all the birds observed during the aerial surveys of Simpson Lagoon (no ground surveys of the lagoon were conducted in 1978) were associated with the lee (south) sides of the barrier islands; wind directions were from northern azimuths (290° to 070°) during all aerial surveys considered. The positive relationship between the northern component of wind and the percent of oldsquaws present along the lee sides of the barrier islands during 1977 and 1978 (see Fig. 22) was highly significant (Spearman $r=0.76$, $n=16$, $P<0.001$), and suggests a remarkable adaptation to the prevailing northerly and northeasterly winds in the Simpson Lagoon area.

Wind Direction at Oliktok	July (Approx. %)*	August (Approx. %)	September (Approx. %)
N	7	6	4
NE	26	21	20
E	24	28	30
S	3	3	4
SW	5	7	10
W	8	9	10

*Data from Brower et al. 1979.

Although Ashmole (1971:235) presented convincing documentation (e.g., Hardy 1967; Ingham and Mahnken 1966; Bennett and Schaefer 1960) that local enrichment and high production often occur in the eddies on the lee sides of islands and over submerged banks, this phenomenon was not observed in the Simpson Lagoon system. However, Griffiths and Dillinger (Ecology of Invertebrates, this volume; Tables 14 and 17) have shown that during 1978 at least two of the three major invertebrate prey (*Mysis relicta* and *Onisimus glacialis*) consumed by oldsquaws were significantly ($P<<0.001$) more abundant in the lagoon, south of the barrier islands, than in the marine system, north of the islands. Furthermore, Griffiths and Dillinger found that within the Simpson Lagoon system, densities of major crustacean invertebrates (mysids and *Onisimus* amphipods) were significantly highest in the deep central portions; their invertebrate sampling stations 78-2,-3 and -4 were all at depths of 2.5 m. In general, oldsquaws were observed

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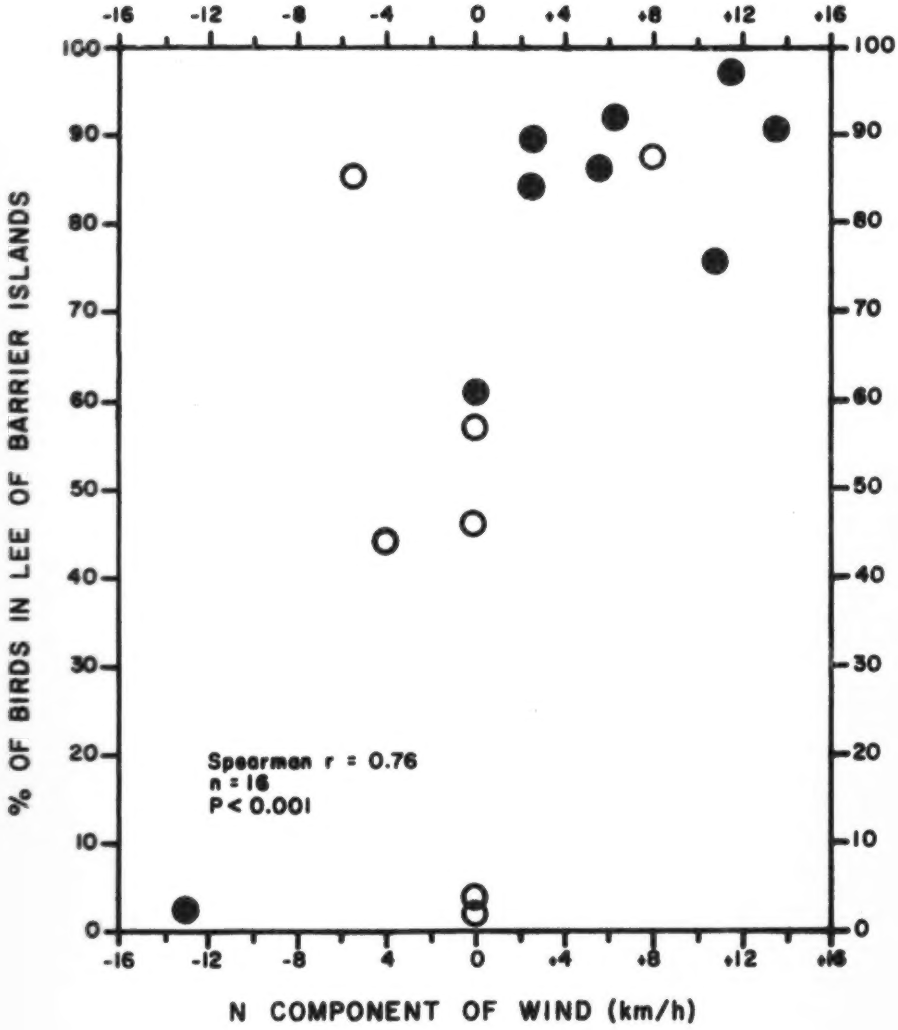

Figure 22. Relationship between wind direction and speed (N component of wind) and the location of oldsquaws in Simpson Lagoon, Alaska during 1977 and 1978. N component of wind = (windspeed) cos (wind direction); negative N component is S component. ○ = 1977 data derived from Table 30 and ● = 1978 data derived from Table 31.

feeding in slightly shallower waters, closer to the lee sides of barrier islands. Twenty-five groups of feeding oldsquaws were collected; the locations of collection had an average depth of 2.1 ± 0.18 m.

The association between molting oldsquaw ducks and barrier island-lagoon systems along the Alaskan and Canadian Beaufort Sea coasts is very significant. Few investigators have documented such an abundance of densely concentrated oldsquaws during the summer molt period in other habitats or in other locations in the Arctic (see Palmer 1976 for a summary). The results of this study suggest that the presence of protective (from wind, waves and ice) barrier islands and the availability of rich supplies of food in adjacent coastal lagoons at least partially account for these dense concentrations of molting (and feeding) oldsquaws in lagoon habitats.

In summary, during the mid-summer period of molt, oldsquaws gather into large flocks and become completely flightless after the loss of their wing feathers. During this period, they are relatively concentrated and are probably more vulnerable to waterborne pollutants and to disturbance than at any other stage of their life cycle; development-related activities in lagoon systems along the Beaufort Sea coast should be conducted with this fact in mind. A recent preliminary study in a lagoon system in the southeastern Beaufort Sea (Sharp 1978) suggests that stationary scaring devices would have limited usefulness in deterring molting oldsquaws from areas of possible contamination, but that slow-moving and low-flying helicopters may be useful to 'herd' both molting and flying oldsquaws away from areas where they concentrate, and hence away from areas of possible contamination.

Post-Molt Period

The estimated number of oldsquaws in Simpson Lagoon on 30 August 1977 and on 15 August 1978, after most males of this species had regained flight, was reduced from the estimated numbers during and immediately after the peak of abundance during the molt (28 July to 5 August 1977 and 15 July to 5 August 1978). Although the female/male ratio remained relatively unchanged throughout August 1977 (1/5 to 1/2.4), apparently some oldsquaws had moved out of Simpson Lagoon by the end of that month. During 1978 the female/male ratio increased drastically during the month of August (1/14 to 1/1.9).

During both 1977 and 1978, a dramatic increase in the estimated number of oldsquaws present in Simpson Lagoon had occurred by 23 September--immediately after lakes and ponds on the mainland tundra had frozen over. An influx of birds from recently frozen tundra areas adjacent to Simpson Lagoon, or from such areas east of Simpson Lagoon, probably accounted for this dramatic increase. During the westward fall migration out of the Beaufort Sea, many oldsquaws follow a coastal route similar to the route followed by some oldsquaws during eastward spring migration (Johnson et al. 1975; see 'MIGRATION' section). It is probable, therefore, that birds from the Canadian portion of the Beaufort Sea, and/or from areas farther east in the Canadian Arctic, may temporarily stop in food-rich lagoons and estuaries such as Simpson Lagoon as they pass westward during late September. The majority of these late-arriving birds are juveniles and females; this explains the increased proportion of female oldsquaws and the presence of juvenile birds during the late September collection periods.

The major dissimilarity between the post molt periods of 1977-78 and 1979 was the absence of the expected influx of primarily female and young-of-the-year oldsquaw in late September, 1979. There is strong evidence that by September 1979, most female and young-of-the-year oldsquaw had not yet moved from inland tundra lakes and ponds, to the coastal lagoons. Table 32 shows the year-to-year differences in temperatures, percent ice-cover on lakes and ponds, percent snow cover on the mainland tundra, and the number of water-associated birds present along Transect 5, the mainland tundra transect approximately 8 km inland from and adjacent to Simpson Lagoon. The temperature was higher and the percent cover by snow and ice was lower in 1979 than in 1977-78.

Although only three species groups and ten individuals were recorded along Transect 5 on 23 September 1979, high densities of birds have seldom been recorded along this transect. The highest densities of oldsquaws recorded on this tundra transect during three years of surveys were 5.8 and 8.6 birds/km^2 on 15 August 1977 and on 28 July 1979, respectively. Even though the oldsquaw is a common species of nesting waterfowl on the Alaskan North Slope, it is difficult to detect from the air. Bartels (1973) has discussed the problems and biases associated with the detection of birds in tundra habitats using various aerial survey techniques.

Table 32. A comparison of weather data and bird sightings along the mainland tundra transect adjacent to Simpson Lagoon, Alaska, during the week prior to the late September aerial survey 1977-79.

Date	Mean Temperature (°C)	Estimated % Ice and Snow Cover			Number of Water-Associated Birds	
		Ponds	Lakes	Tundra	# of Species Groups	# of Individuals
16-22 Sept. 1977	-1.6	100	95	99	0	0
17-23 Sept. 1978	-0.2	95	85	90	0	0
17-23 Sept. 1979	+0.7	45	35	5	3*	10*

*Four loons, 5 gulls and 1 unidentified duck.

Thus, unseasonably warm weather along portions of the Alaskan North Slope during late September 1979 and the consequent large amount of open water available to waterfowl, and the presence in these habitats of several species of water-associated birds (including ducks), provide strong circumstantial evidence that many oldsquaws had not yet moved from tundra lakes and ponds to lagoon habitats.

Oldsquaws in Areas Other Than Simpson Lagoon

The total number of post-breeding oldsquaws that use the protected lagoons and bays along the north coast of Alaska is not precisely known. In his review of major molting locations of oldsquaws in the Nearctic, Palmer (1976:362) does not mention the coastal lagoons and barrier islands along the north coast of Alaska.

The area between Thetis Island and the U.S.-Canada border provides an extensive chain of protected barrier island-lagoon systems. Aside from the Plover Islands, the area of coast between Thetis Island and Point Barrow is generally lacking such barrier islands and lagoons. Even so, such areas as Teshekpuk Lake, Harrison Bay, Smith Bay, and Admiralty Bay provide large areas of protected water for molting and post molting concentrations of seaducks. During shipboard surveys in August and September of 1971, Bartels (1973) recorded large numbers of post-breeding oldsquaws in the nearshore waters between Point Barrow and the Sagavanirktok River delta. He calculated that 90% and 84%, respectively, of the total number of oldsquaws that he recorded during his surveys in 1971 were in waters within 18 and 8 km from shore. Furthermore, approximately 88% of the total number of oldsquaws that Bartels recorded were in relatively shallow waters near the coast. During the helicopter surveys conducted in these shallow waters, Bartels recorded densities of oldsquaws ranging from 41.3 to 530.9 birds/km^2 in the area between Pt. Barrow and the Sag Delta. Bartels extrapolated his average nearshore density of 173.4 oldsquaws/km^2 across his study area in order to estimate that approximately 337,000 post-breeding individuals may have used this area during 18 August to 18 September 1971.

Judging from the results of our 1978 and 1979 aerial surveys from the Colville Delta eastward to the U.S.-Canada border, we suggest that densities and numbers of post-breeding oldsquaws are higher along this more protected eastern half of the Alaskan Beaufort coast than along the western half. Thus, we conservatively estimate that over one-half million oldsquaws may occupy the north coast of Alaska during the post-breeding season. The fact that over 100,000 oldsquaws were calculated to be present in one barrier island-lagoon system (Jones Islands-Simpson Lagoon) late during the post-breeding period in 1977 (see Table 20, this volume) lends credibility to the above estimate.

Harrison (1977) conducted aerial surveys in the Beaufort Sea during July and August 1976. During July, he recorded densities from 10 to 99.9 oldsquaws/km^2 at several coastal locations between Beaufort Lagoon and Reindeer Island (Fig. 2). An interesting feature of Harrison's July results is that moderate densities (1.1 to 30.0 birds/km^2) of oldsquaws were recorded in far offshore locations, in the Beaufort Sea pack ice. During August, Harrison's recorded mean density of oldsquaws on all transects was only 3.4 birds/km^2; locally high densities of from 30 to greater than 100 oldsquaws/km^2 were recorded at coastal locations between Anderson Point and Griffin Point, to the west and east, respectively, of Barter Island. During this same month locally high densities of oldsquaws were recorded along the coast south of the Maguire Islands and in Leffingwell Lagoon. Few oldsquaws were recorded at offshore locations during Harrison's August survey.

During the 4-day period 18-21 July 1973 over 31,000 post-breeding (molting) oldsquaws were counted in the nearshore waters along the 538.8 km section of coastline between Shingle Point, Yukon Territory, and Prudhoe Bay, Alaska (Gollop and Richardson 1974). Approximately 65% of the total 31,000 birds were recorded in 16 areas of concentration along the north coast of Alaska. Those areas of greatest concentration are listed in Table 33.

Three other surveys were conducted along the northeast coast of Alaska during 1973 (LGL Ltd. unpublished data). (1) The survey conducted on 17-18 June 1973 indicated that, aside from minor concentrations in areas of open water near river deltas, few oldsquaws were present along the north coast of Alaska. (2) Few oldsquaws were detected during the survey conducted on 29 July 1973 (4352 between Prudhoe Bay and the U.S.-Canada border); however, that survey did not include many mid-lagoon and barrier island locations. Major concentrations on 29 July 1973 were located in Camden Bay,

Table 33. Abundance and concentration areas of oldsquaws along the north coast of Alaska during 18-21 July 1973*. (Data are from Gollop and Richardson 1974.)

Areas of Concentration	Number of Oldsquaw
South of Flaxman Island	5,033
Simpson Cove	3,100
S of Arey Island	1,612
S of North Star Island	1,300
S of Tigvariak Island	1,141
S of Bullen Point	1,000
Total Nine Other Concentration Areas	7,063
Remaining Scattered Flocks	11,004
Total	31,253

*The oldsquaw molt period.

behind Arey Island, in Kaktovik Lagoon, in Tapkaurak Lagoon, in Pokok Bay and in Angnun Lagoon. (3) The last coastal survey conducted by LGL during 1973 was on 30 August. On that date 25,040 oldsquaws were recorded along the northeast coast of Alaska. Major concentrations were seen off the Sag River delta, in the protected waters behind the Maguire, Stockton and McClure islands, behind Flaxman Island, offshore from Camden Bay (approximately 8000 individuals) and offshore from Barter Island (approximately 10,000 individuals).

Spindler (1979) conducted aerial surveys along the coast of the Arctic National Wildlife Range during August and September of 1979. His survey procedures and transect locations were similar to ours along this portion of the Arctic coast. Spindler's first survey was conducted on 1 August and was approximately along our Transect 14 (his transect terminated at Barter Island; ours terminated at Arey Island). On this date and in this area he recorded a density of 97.9 oldsquaws/km^2, which was radically less than the 373.8 birds/km^2 that we recorded there three days earlier on 29 July. The reason for this apparent decline in the number of oldsquaws (from approximately 14,000 birds to approximately 4000 birds) is not clear. It is conceivable that our earlier assumption regarding the timing of the molt by male oldsquaws during 1979 was incorrect. If so, then the molt may have begun early in July rather than late in July, as we had assumed. Thus, it is possible that by 1 September some oldsquaws may have completed their wing molt and may have been able to fly out of the survey area. However, since most of the lagoon systems along the coast of northeast Alaska were not free of ice until 14 July, it is unlikely that the initiation of the molt began earlier than a week later, during the fourth week of July. Male oldsquaws only reluctantly fly on wings that are less than 19-20 cm long. After they molt their flight feathers, oldsquaws require approximately 12-14 days for their wings to grow to 19-20 cm (Table 25). Therefore, the earliest date when oldsquaws may have been able to fly, if they began the molt during the fourth week of July, was during the period 2 to 4 August.

Another possible explanation for the apparent decline in the oldsquaw density between 29 July and 1 August 1979 may be that large numbers of oldsquaws swam, rather than flew, from the transect area. A much larger proportion of transect 14, compared with other transects, lies along the exposed coast between Konganevik Point and Anderson Point. On 29 July we recorded over 8400 oldsquaws on-transect between these two points. Thus, it is possible that many of the 8400 oldsquaws recorded in this area on 29 July were offshore from the coast on 1 August (out of the transect area) and were undetected. The subtraction of these 8400 oldsquaws from our on-transect count recorded on 29 July would reduce the density from 373.8 birds/km^2 to 139.2 birds/km^2. The difference between 139.2 and 97.9 birds/km^2 represents approximately 1500 oldsquaws, and could be attributable to factors such as variability in an observer's detection and estimation skills, the state of the sea, or fog conditions.

Spindler's second 1979 aerial survey along the coast of the Arctic National Wildlife Range was during the period 7 to 10 September. Along portions of our Transect 14 on 10 September, he recorded only 234 oldsquaws (8.1 birds/km^2); along Transect 15 on 7 and 10 September, he recorded 2027 oldsquaws (56.2 birds/km^2). Thus, along the 162 km of coast between Konganevik Point and Demarcation Bay, only 2256 oldsquaws (38.4 birds/km^2) were recorded. This was a marked decline from the density recorded along portions of this coast during early August. As mentioned earlier, however, the period from mid or late August to early September traditionally has been a period of decline in the abundance of oldsquaws at barrier island-lagoon locations along the coast of northeastern Alaska. In Simpson Lagoon this decline is coincident with a decline in the ratio of male:female oldsquaws.

During our investigations of oldsquaws in the post molt period in the Simpson Lagoon area, we have not recorded many oldsquaws migrating eastward or westward along the coast. Such movements probably would have been detected if male oldsquaws were leaving the coastal Beaufort Sea area for locations east or west of there. Similarly we have not recorded large scale migrations northward or southward from the lagoons. A movement southward by large numbers of oldsquaws would be unlikely during this period since tundra wetland habitat is relatively saturated with female oldsquaws and their broods. A movement northward by large numbers of oldsquaws seems most likely and could easily occur without being noticed. The fact that the highest densities of oldsquaws along the offshore marine transect (Transect 1;

1.6 km seaward of the Jones Islands) normally are recorded during the period 15 August to 15 September (see Table 17) supports the hypothesis that oldsquaws, primarily males, move seaward into offshore marine habitats during late August and early September. During aerial surveys conducted on 30 August 1973 (LGL Ltd. unpubl. data), large flocks of oldsquaws were recorded at offshore locations north of Camden Bay (8000 birds) and north of Barter Island (10,000 birds), and in late August 1977, after most oldsquaws in the Simpson Lagoon area had regained flight, small flocks were observed flying seaward of the barrier islands and landing among the ice floes that had moved close to the coast at that time. Divoky (1978a: 407, 419 and 432) recorded significant numbers of oldsquaws at locations far offshore in the Beaufort Sea during August and September and reported (1978a:482) that in September oldsquaws arrived in Elson Lagoon (SE of Point Barrow) from the north.

Four oldsquaws from a group that appeared to be feeding among ice floes were collected 300 m offshore from Pingok Island on 27 August 1977. The stomachs of all four birds contained large numbers (see table below) of the ice associated amphipod *Apherusa glacialis* (see Griffiths and Dillinger, Ecology of Invertebrates, this volume, for more information on *A. glacialis*).

A. glacialis in four oldsquaw stomachs

1		2		3		4	
#	g*	#	g	#	g	#	g
58	0.48	105	0.52	42	0.33	15	0.09

*grams wet weight.

An inspection of the ice floes in the general area where the birds were feeding revealed large numbers of *A. glacialis* on the under ice surfaces. Amphipod traps set in the benthos in this area caught very large numbers of *Onisimus glacialis* and small numbers of *A. glacialis*. Thus oldsquaws were probably feeding from the undersides of the ice pans where *Apherusa* were dense.

In the absence of ice-associated invertebrates, oldsquaws could easily feed from the epibenthos in offshore regions. More than any other species of sea duck, oldsquaws are adapted for feeding in deep water at offshore marine locations. They are unique in their manner of diving. They 'fly' through the water, using the full area of their wings, in a manner similar to that of the auks (Johnsgaard 1975). They can dive to depths of nearly 70 m (Palmer 1976; Peterson and Ellarson 1979). The area up to about 50 km offshore from the Jones Islands is less than 70 m deep. Thus oldsquaws could feed on the high densities of amphipods and mysids present in the marine epibenthos at offshore locations (see Results of invertebrate sampling from Station 7, Griffiths and Dillinger, Ecology of Invertebrates, this volume).

PREMIGRATORY STAGING

Results

Shorebirds

Although phalaropes were not the only species of shorebirds observed in the study area during 1977 and 1978, they were the most common shorebirds recorded and they were highly concentrated, especially during 1977, at certain shoreline locations in the study area during mid August. Therefore, phalaropes were considered key species. Other species of birds recorded on shoreline transects but thought to be of less relative importance than phalaropes are shown in Appendix VIII.

The movement of juvenile phalaropes from rearing areas on the tundra to coastal staging areas was, in 1977, first noted at Pingok Island on 1 August. On this date a total of 150 red phalaropes were recorded on 15 shoreline transects in the study area. During 1977 no northern phalaropes were recorded during transect surveys in the study area until 3 August (Table 34). During 1978, red and northern phalaropes (37 and 6 birds, respectively) were first recorded along the barrier islands on 4 August.

The overall ratio of northern to red phalaropes recorded in the study area during the month of August was 1:4.0 in both 1977 and 1978. During 1977, this ratio was 0:150 on 1 August before northern phalaropes had arrived in the study area, 1:2.8 on 16 August during the peak of phalarope abundance, and 1:1.4 on 26 August--the last date when both species were recorded in the study area. Seventeen red phalaropes (in winter plumage) were recorded on Pingok Island on 14 September; these were the last phalaropes seen in the study area during 1977.

During 1978, the ratio of northern to red phalaropes varied from 0:277 on 14 August during the peak of phalarope abundance to 1:2.1 during the survey on 29 August. Although the overall ratio of northern to red phalaropes (1:4.0) was the same during 1977 and 1978, the number of phalaropes recorded during 1978 was much smaller than that during 1977 (Table 34). Even though no phalaropes were recorded in the Simpson Lagoon area after 3 September 1978, two small flocks (4 and 8 birds, respectively)

Table 34. Numbers of red and northern phalaropes observed on beach transects in the Simpson Lagoon-Jones Islands area during August, 1977 and 1978. Each of the 15 standardized transects was 1 km long; the extra single transect was 1.2 km long.

	August 1977											
	1	2	3	6	8	12	14	16	23	24	26	Total
Number of Red Phalaropes	150	4	77	193	525	69	16	3470	262	1340	24	6130
Number of Northern Phalaropes	0	0	53	60	51	23	0	1220	52	40	17	1516
Northern/Red Ratio	0/150	0/4	1/1.5	1/3.3	1/10.3	1/3	0/16	1/2.8	1/5	1/33.5	1/1.4	1/4.0
Number of Transects Surveyed	15	1	1	1	1	1	1	15	1	15	1	53

	August 1978															
	2	4	7	9	11	13	14	17	19	21	24	26	28	29	31	Total
Number of Red Phalaropes	0	37	0	23	22	4	277	4	242	0	104	7	0	232	97	1049
Number of Northern Phalaropes	0	6	0	2	0	0	0	0	103	0	10	1	0	112	27	261
Northern/Red Ratio	0/0	1/6.2	0/0	1/11.5	0/22	0/4	0/277	0/4	1/2.4	0/0	1/10.4	1/7	0/0	1/2.1	1/3.6	1/4.0
Number of Transects Surveyed	1	16	1	16	1	1	16	1	16	1	16	1	1	16	1	105

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were recorded in an area of open water near the ARCO causeway (Prudhoe Bay) on 14 and 15 October 1978.

During August and early September of 1977 and 1978, densities of shorebirds differed significantly among the three types of beach transects surveyed (for 1977, Friedman χ_r^2=6.4, k=3, n=5, P=0.04; for 1978, χ_r^2=11.1, k=3, n=8, P=0.002--see Table 35 and Siegel 1956). During both years, mean densities were highest along oceanside beaches of the barrier islands, intermediate along lagoonside beaches of these islands, and lowest along mainland beaches.

During August of 1978, markedly fewer phalaropes were recorded in the study area than during the same month in 1977 (Tables 35 and 36).

The dates of peak densities of phalaropes along barrier island beaches were similar in 1977 and 1978, except that the peak density on the seaward beaches was recorded earlier in 1977 than in 1978, whereas the peak density along the lagoonside beaches was earlier in 1978 than in 1977 (Table 35). During both 1977 and 1978 phalaropes were recorded along mainland beaches only during the period of their peak abundance in the study area (29.8 birds/km on 16 August 1977 and 1.0 and 2.4 birds/km on 19 and 24 August 1978; Table 35). Few phalaropes were present in the study area after the end of August in 1977 and after 3 September 1978.

During August of both 1977 and 1978, red phalaropes accumulated a substantial amount of fat during the period of pre-migratory staging in the study area (Table 37). Northern phalaropes in both years arrived in the study area substantially fatter than red phalaropes and no distinct increase in fatness of northern phalaropes was noted during August.

All phalaropes collected for the feeding studies during both 1977 and 1978 were juveniles. Sex ratios of both species of phalaropes varied greatly between collection periods (Table 37). For both species during 1977, the proportion of females was lower on 19-25 August than on 3-12 August, but the difference was not statistically significant for either species. During 1978, the opposite was true; the proportion of females of both species was lower (although not statistically so) during the 6-18 August period than during the 20-31 August period.

To summarize, significant numbers of phalaropes were present in the study area only during August, although some flocks apparently remain along

Table 35. Average linear densities (birds/km of shoreline)* of all shorebirds recorded on three beach types surveyed during 1977 and 1978.

Date of Survey	Beach Type					
	Barrier Island Oceanside Beach (n=5)		Barrier Island Lagoonside Beach (n=5)		Mainland Beach (n=5)	
	1977	1978	1977	1978	1977	1978
31 July	-	6.2(1.0)	-	0.0(0.0)	-	2.6(0.0)
1 August	5.0(4.0)[†]	-	2.2(1.2)	-	1.6(0.0)	-
4 August	-	9.4(7.0)	-	1.6(1.6)	-	0.0(0.0)
9 August	-	2.0(2.0)	-	3.0(3.0)	-	0.0(0.0)
14 August	-	0.2(0.2)	-	54.2(53.8)	-	0.6(0.0)
16 August	132.3(131.8)	-	38.0(32.8)	-	32.8(29.8)	-
19 August	-	36.0(34.8)	-	36.4(35.0)	-	5.2(1.0)
24 August	2.2(0.0)	15.2(14.8)	39.8(32.6)	26.4(23.8)	1.2(0.0)	7.6(2.4)
29 August	-	67.4(61.6)	-	18.4(17.4)	-	3.4(0.0)
1 September	11.2(0.0)	-	3.0(0.0)	-	3.8(0.0)	-
3 September	-	0.6(0.4)	-	24.0(12.6)	-	0.0(0.0)
14 September	15.0(0.0)	-	2.0(0.0)	-	0.0(0.0)	-

*Beach transects were 1 km long x 20 m wide (10 m either side of the shoreline) = 0.02 km^2. Only those birds seen on transect have been included in this table.

[†] Parentheses enclose the mean densities of all phalaropes (red, northern and unidentified phalaropes) recorded during each survey.

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Table 36. Estimated numbers of shorebirds and gulls/terns present along the oceanside and the lagoonside beaches of the Jones Islands from Spy to Cottle Island, and along the mainland beach of Simpson Lagoon from Oliktok Point to Beechey Point, 1977 and 1978.

	Beach Type					
	Barrier Island Oceanside Beach (30.5 km long)		Barrier Island Lagoonside Beach (34.2 km long)		Mainland Beach (32.2 km long)	
Date of Survey* and Species	1977	1978	1977	1978	1977	1978
31 July						
All Shorebirds	-	189(31)	-	0(0)	-	84(0)
All Gulls/Terns	-	37(37)	-	7(0)	-	19(19)
1 August						
All Shorebirds	153(122)†	-	75(41)	-	52(0)	-
All Gulls/Terns	24(18)**	-	109(21)(14)	-	6(6)	-
4 August						
All Shorebirds	-	287(44)	-	55(55)	-	0(0)
All Gulls/Terns	-	18(18)	-	0(0)	-	6(6)
9 August						
All Shorebirds	-	61(61)	-	103(103)	-	0(0)
All Gulls/Terns	-	6(6)	-	27(7)	-	0(0)
14 August						
All Shorebirds	-	6(6)	-	1854(1840)	-	19(0)
All Gulls/Terns	-	0(0)	-	55(41)	-	6(6)
16 August						
All Shorebirds	4035(4020)	-	1300(1122)	-	1056(960)	-
All Gulls/Terns	79(6)(6)	-	1156(27)	-	6(6)	-
19 August						
All Shorebirds	-	1098(1061)	-	1245(1197)	-	169(32)
All Gulls/Terns	-	18(15)	-	0(0)	-	0(0)
24 August						
All Shorebirds	67(0)	464(451)	1361(1115)	903(814)	39(0)	245(77)
All Gulls/Terns	24(24)	6(6)	150(150)	0(0)	0(0)	0(0)
29 August						
All Shorebirds	-	2056(1879)	-	625(595)	-	110(0)
All Gulls/Terns	-	55(55)	-	0(0)	-	0(0)
1 September						
All Shorebirds	342(0)	-	103(0)	-	122(0)	-
All Gulls/Terns	451(451)	-	0(0)	-	13(13)	-
3 September						
All Shorebirds	-	18(12)	-	821(431)	-	0(0)
All Gulls/Terns	-	49(49)	-	185(185)	-	32(32)
14 September						
All Shorebirds	458(0)	-	68(0)	-	0(0)	-
All Gulls/Terns	31(31)	-	27(27)	-	0(0)	-

*Beach transects were 20 m wide (10 m either side of the shoreline) and 1 km long. Estimates are based on mean densities of birds recorded during each survey along 5 transects on each type of beach.

†Parentheses enclose the estimated number of all phalaropes present along the beach type.

**Parentheses enclose the estimated number of glaucous gulls present along the beach type. Where two parenthetical values appear, the first refers to glaucous gulls and the second refers to Sabine's gulls.

Table 37. Changes in subcutaneous fatness* and sex ratios of red and northern phalaropes in Simpson Lagoon during August, 1977 and 1978. All specimens were juveniles.

Species	August 1977								
	3	4	5	6	12	19	21	23	25
Red Phalarope									
Fatness $\bar{x}$	2.4	2.1	2.4	2.3	2.7	3.0	3.2	4	3.3
S.D.	0.55	0.30	1.14	0.50	0.82	0.89	0.98	0	0.98
n	5	11	5	4	6	6	6	1	12
Sex Ratio (M/F)	3/2	5/6	3/2	1/3	1/2†	6/0	4/1†	-†	5/5†
Northern Phalarope									
Fatness $\bar{x}$	-	3.5	3.5	3.0	3.4	-	4.5	3.8	4
S.D.	-	0.58	0.71	0	1.41	-	0.58	0.84	0
n	-	4	2	4	8	-	4	5	1
Sex Ratio (M/F)	2/2	2/0†	2/0	1/1†	1/5†	3/1	3/1	1/0†	-

...Continued

Species	August 1978														
	6	7	10	12	17	18	20	21	22	23	26	27	28	30	31
Red Phalarope															
Fatness $\bar{x}$	1.3	2	2	2	3	2.5	2.5	3.5	2	2	3.3	-	3.5	4	2
S.D.	0.75	-	0.5	-	0.33	0.4	0.4	0.29	-	-	0.30	-	0.29	0.25	-
n	3	1	3	1	2	6	2	2	1	1	3	-	2	3	1
Sex Ratio (M/F)	2/0[†]	1/0	2/0[†]	0/0[†]	1/1	2/3[†]	0/2	1/1	0/1	1/0	1/2	-	1/1	1/2	1/0
Northern Phalarope															
Fatness $\bar{x}$	-	-	2.3	4	4	2.8	3	4	2	2	-	2.7	-	3	3
S.D.	-	-	0.43	-	0.25	0.35	0.33	-	0.5	-	-	0.38	-	0.33	-
n	-	-	3	1	2	6	2	1	3	1	-	3	-	3	1
Sex Ratio (M/F)	-	-	2/1	1/0	1/1	2/3[†]	1/1	0/1	2/1	0/1	-	0/2[†]	-	1/2	0/1

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*Fatness classifications conform to OCS fatness codes: 1=no fat; 2=light fat; 3=moderate fat; 4=heavy fat; 5=excessive fat.

[†] Some birds of undetermined sex were collected on this day.

the Beaufort Sea coast until freeze-up is nearly complete. Markedly fewer phalaropes were recorded in the Simpson Lagoon-Jones Islands study area in 1978 than in 1977. During the month of August of both 1977 and 1978 red phalaropes accumulated fat and outnumbered northern phalaropes by a ratio of 4.0:1. The period of peak phalarope abundance was during mid to late August when high densities were recorded along oceanside (the highest densities) and lagoonside beaches of barrier islands. Few phalaropes were recorded along mainland beaches during either year of study.

Arctic Tern

Although some arctic terns nested in the study area, all large groups of this species were transients. A relatively large westward movement of arctic terns through the study area occurred during mid August of 1977 (Tables 36 and 38). Peak numbers recorded during the 15 August 1977 aerial survey were along the barrier islands (Transect 2) where a total of 355 were observed. During this survey no arctic terns were observed in offshore marine habitats, in mid-lagoon habitats or in tundra habitats.

In general, far fewer arctic terns were recorded in the Jones Islands-Simpson Lagoon study area during 1978 than in 1977. During 1978 the field camp and migration watch station were located near the mainland coast rather than on Pingok Island where they had been during 1977. Probably for that reason, westward fall migration of arctic terns was recorded along the barrier islands in August 1977 but not in 1978. However, the peak of tern abundance in the study area in 1978 was again recorded during aerial surveys conducted on 15 August at barrier island locations (Table 39). During the aerial survey programs of both 1977 and 1978, the majority of all arctic terns recorded in the study area (98.2% in 1977 and 86.5% in 1978) were recorded at locations along the barrier islands (see Table 39). The fact that a few arctic terns were recorded at nearshore marine locations seaward of the Jones Islands during late August of both 1977 and 1978 suggests that a westward fall movement may occur there or that terns may feed at locations seaward of as well as along the barrier islands. During the entire two-year study only five arctic terns (three during 1977 and two during 1978) were observed during aerial surveys along the mainland

Table 38. Average linear densities (birds/km of shoreline)* of gulls and terns[†] recorded on three beach types surveyed during 1977 and 1978.

Date of Survey	Beach Type					
	Barrier Island Oceanside Beach (n=5)		Barrier Island Lagoonside Beach (n=5)		Mainland Beach (n=5)	
	1977	1978	1977	1978	1977	1978
31 July	-	1.2(1.2)	-	0.2(0.0)	-	0.6(0.6)
1 August	0.8(0.6)	-	3.2(1.0)	-	0.2(0.2)	-
4 August	-	0.6(0.6)	-	0.0(0.0)	-	0.2(0.2)
9 August	-	0.2(0.2)	-	0.8(0.2)	-	0.0(0.0)
14 August	-	0.0(0.0)	-	1.6(1.2)	-	0.2(0.2)
16 August	2.6(0.4)	-	33.8(0.8)	-	0.2(0.2)	-
19 August	-	0.6(0.5)	-	0.0(0.0)	-	0.0(0.0)
24 August	0.8(0.8)	0.2(0.2)	4.4(4.4)	0.0(0.0)	0.0(0.0)	0.0(0.0)
29 August	-	1.8(1.8)	-	0.0(0.0)	-	0.0(0.0)
1 September	14.8(14.8)	-	0.0(0.0)	-	0.4(0.4)	-
3 September	-	1.6(1.6)	-	5.4(5.4)	-	1.0(1.0)
14 September	1.0(1.0)	-	0.8(0.8)	-	0.0(0.0)	-

*Beach transects were 1 km long x 20 m wide (10 m either side of the shoreline) = 0.02 km^2. Only those birds seen on transect have been included in this table.

[†] Parentheses enclose the mean densities of all gulls (both glaucous and Sabine's gulls) recorded during each survey. To determine the linear density of arctic terns, subtract the density within the parentheses from the number immediately to the left.

Table 39. Total numbers of terns recorded during aerial surveys of five transects in the Jones Islands-Simpson Lagoon area, June to September 1977-78.

Date	Transect #					Total
	1	2	3	4	5	
1977						
5 June	0 (0)[†]	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
20 June	0 (0)	10 (0)	0 (0)	0 (0)	0 (0)	7 (0)
5 July	0 (0)	22 (0)	0 (2)	0 (0)	0 (0)	22 (2)
28/29 July*	0 (0)	23 (36)	0 (2)	3 (0)	0 (0)	26 (38)
15 August	- (-)	355 (1)	- (-)	0 (0)	0 (0)	355 (1)**
30 August	5 (0)	109 (0)	0 (0)	0 (0)	0 (0)	114 (0)
22 September	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1978						
23 June	0 (0)*	3 (0)	0 (0)	0 (0)	0 (0)	3 (0)
5 July	0 (0)	12 (0)	0 (0)	0 (0)	0 (0)	12 (0)
15 July	0 (0)	12 (4)	0 (0)	2 (0)	1 (0)	15 (4)
25 July	0 (0)	3 (0)	0 (0)	0 (0)	0 (0)	3 (0)
5/6 August	0 (0)	2 (3)	0 (0)	0 (0)	0 (0)	2 (3)
15 August	0 (0)	35 (3)	0 (0)	0 (0)	0 (0)	35 (3)
25 August	9 (0)	0 (0)	0 (0)	0 (0)	0 (0)	9 (0)
5 September	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
15 September	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
23 September	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

*Transects 1 and 3 were surveyed on 29 July 1977; Transects 2, 4 and 5 were surveyed on 28 July 1977.

[†] Parentheses enclose the number of terns recorded off-transect (>200 m from either side of the aircraft).

**Minimum number.

shoreline of the study area. The few arctic terns that nested in an area of lakes and ponds SW of the mainland tundra nesting plot (Plot 3; Fig. 1) were commonly observed flying to and from the barrier islands to feed.

Terns concentrated to feed at several locations along the barrier islands during fall westward movements. The most notable of these concentration areas during 1977 were at the east ends of Spy Island (about 220 observed on 16 August) and Pingok Island (maximum of 167 observed on 16 August). During 1978, the only feeding concentration of terns noted in the study area was of approximately 10 individuals recorded at the east end of Pingok Island on 29 August.

The detailed survey of barrier island beach transects on 16 August 1977 indicated that the number of arctic terns was greater along the lagoonside beaches of the barrier islands (33.0 terns/km of shoreline) than along the oceanside beaches of the islands (2.2 terns/km) or the mainland beaches (no terns observed). Based on these results, the estimated numbers of arctic terns along all beaches in the study area on 16 August 1977 were as follows: barrier island oceanside shorelines, 67 arctic terns; barrier island lagoonside shorelines, 1129; mainland shorelines, none (Tables 35 and 36). Only 109 arctic terns were observed during the 30 August 1977 aerial survey of the barrier islands. No terns were recorded in the study area after 30 August 1977 or after 25 August 1978.

During 1978, the only significant numbers of arctic terns recorded in the study area were during shoreline surveys on 9 and 14 August (Table 38) and during the 15 August aerial survey along the barrier island shoreline of Simpson Lagoon (Transect 2; Table 39).

As mentioned earlier, no intensive field program was conducted in the Jones Island-Simpson Lagoon study area during 1979. During the four aerial surveys conducted in 1979, only one arctic tern was recorded on-transect in the Jones Islands-Simpson Lagoon study area (Table 40). That tern was recorded along the south side of Leavitt Island during the 28 July aerial survey. Four arctic terns were recorded off-transect at this same location during the preceding survey on 22 June 1979.

The density of arctic terns in Simpson Lagoon during 1978 and 1979 was not significantly different from that at locations east and west of Simpson Lagoon (Tables 41 and 42). Of the total 148 and 61 terns seen on-transect

Table 40. Total numbers of terns recorded during aerial surveys of five transects in the Jones Islands-Simpson Lagoon area, June to September 1979.

Transect #	22 June	28/29 July	31 Aug.-1 Sept.	23 Sept.
1	0 (0)*	0 (0)	0 (0)	0 (0)
2	0 (4)	1 (0)	0 (0)	0 (0)
3	0 (0)	0 (0)	0 (0)	0 (0)
4	0 (0)	0 (0)	0 (0)	0 (0)
5	0 (0)	0 (0)	0 (0)	0 (0)
Total	0 (4)	1 (0)	0 (0)	0 (0)

*Parentheses enclose the number of terns recorded off-transect (>200 m from either side of the aircraft). Numbers to the left of parentheses are birds seen on-transect.

Table 41. Numbers of arctic terns recorded on- and off-transect along various sections of the Beaufort Sea coast of northeastern Alaska, June to September 1978.

	West of Simpson Lagoon*			Simpson Lagoon			East of Simpson Lagoon†		
		# Terns			# Terns			# Terns	
Survey Date	# km² Surveyed	on	off	# km² Surveyed	on	off	# km² Surveyed	on	off
23 June	12.0	0	0	39.9	3	0	31.3	0	1
5 July	65.5	0	0	39.3	12	2	322.8	13	4
15 July	12.0	0	0	39.9	14	4	31.3	0	0
25 July	65.5	0	0	39.9	3	0	162.0	1	3
5 August	65.5	0	0	39.9	2	3	315.1	6	6
15 August	12.0	0	0	39.9	35	3	31.3	4	12
25 August	5.5	0	0	39.9	0	0	126.9	28	0
5/6 September	65.5	0	0	39.9	0	0	315.1	27	0
15 September	12.0	0	0	39.9	0	0	31.3	0	0
23 September	12.0	0	0	39.9	0	0	126.9	0	0
All Dates	327.5	0	0	399.2	69	12	1393.9	79	26
Mean Density		0.00			0.17			0.06	

*This area included as many as six transects (163.7 km x 0.4 km = 65.5 km²); it extended as far west as Atigaru Pt. and included most of the Colville River delta (see Figure 2A-B).

†This area included as many as 11 transects (787.8 km x 0.4 km = 315.1 km²); it extended as far east as the Canada-U.S. border and as far north as the Midway Islands, north of Prudhoe Bay (see Figure 2C-G).

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Table 42. Numbers of arctic terns recorded on- and off-transect along various sections of the Beaufort Sea coast of northeastern Alaska, June to September 1979.

	West of Simpson Lagoon*			Simpson Lagoon			East of Simpson Lagoon†		
	# km² Surveyed	# Terns		# km² Surveyed	# Terns		# km² Surveyed	# Terns	
Survey Date		on	off		on	off		on	off
22 June	65.5	2	1	39.9	0	4	93.8	1	0
28/29 July	65.5	4	1	39.9	1	0	222.3	53	3
31 Aug.-1 Sept.	65.5	0	0	39.9	0	0	13.9	0	0
23 Sept.	65.5	0	0	39.9	0	0	31.3	0	0
All Dates	262.0	6	2	159.6	1	4	361.3	54	3
Mean Density		0.02			0.01			0.15	

*This area included as many as six transects (163.7 km x 0.4 km = 65.5 km²); it extended as far west as Atigaru Pt. and included most of the Colville River delta (see Figure 2A-B).

†This area included as many as 11 transects (787.8 km x 0.4 km = 315.1 km²); it extended as far east as the Canada-U.S. border and as far north as the Midway Islands, north of Prudhoe Bay (see Figure 2C-G).

in lagoon habitats during 1978 and 1979, 135 (91%) and 50 (82%), respectively, were seen along the south sides of barrier islands.

Glaucous Gull

Of the total of 1112 glaucous gulls recorded during aerial surveys in Simpson Lagoon during 1978, 95.1% (1058) were seen at shoreline locations (Transects 2 and 4) and 80.9% (856) of these birds were observed along barrier island shorelines (Transect 2; Table 43).

Although mid-lagoon waters were little used in either year, considerably more glaucous gulls were recorded at mid-lagoon locations in Simpson Lagoon during 1978 than during 1977 (20 during 1978; two during 1977). Only six glaucous gulls were seen during 1978 along the transect seaward of the Jones Islands, and only four were seen there during 1977. Similarly, a total of only 28 glaucous gulls were seen in 1978 during surveys of the mainland tundra transect approximately 7 km inland from Simpson Lagoon; 27 were seen there during surveys in 1977 (a few glaucous gulls nest at inland locations).

During 1977, the number of glaucous gulls recorded along shoreline habitats of the study area did not exceed 27 birds (1.9 birds/km^2; Transect 2; 5 July 1977) until 28 July. On this date a total of 98 glaucous gulls (3.5 birds/km^2) were recorded along the mainland shoreline (Table 43).

By 15 August 1977, the density of glaucous gulls along the barrier islands had more than doubled since the previous survey (from 3.5 to 7.6/km^2). The 112 glaucous gulls seen along the barrier islands on 15 August represented 88% of the total number recorded during the aerial survey on that date. The mid-lagoon portion of the study area was not surveyed on 15 August, but along the mainland shoreline the number of glaucous gulls had declined from 7.6 to 1.1 birds/km^2 (from 98 to 14 birds seen on-transect).

By 30 August 1977, the number of glaucous gulls observed in the study area had increased most markedly along the barrier islands (Transect 2), where a density of 25.5 birds/km^2 (377 gulls) was recorded. The number of glaucous gulls seen on this transect represented 94% (377 of 399 gulls) of the total number seen on-transect during this aerial survey. The estimated total number of glaucous gulls present along the barrier islands on

Table 43. Total numbers of glaucous gulls recorded in all habitats during aerial surveys of five transects in the Jones Islands-Simpson Lagoon area, 1977-78.

	Transect #					
Date	1	2	3	4	5	Total
1977						
5 June	0 (0)[+]	20 (0)	1 (1)	1 (1)	2 (1)	24 (3)
20 June	0 (0)	2 (0)	0 (0)	2 (0)	3 (0)	7 (0)
5 July	0 (0)	23 (0)	0 (0)	4 (1)	1 (3)	28 (4)
28/29 July*	1 (0)	52 (4)	0 (0)	98 (1)	2 (0)	153 (5)
15 August	- (-)	112 (0)	- (-)	14 (0)	1 (1)	127 (1)
30 August	1 (25)	377 (44)	0 (0)	18 (0)	3 (0)	399 (69)
22 September	0 (0)	2857 (52)	0 (0)	240 (5)	0 (0)	3097 (57)
1978						
23 June	1 (0)*	34 (0)	0 (0)	1 (0)	0 (0)	36 (0)
5 July	2 (0)	23 (8)	0 (0)	1 (1)	0 (6)	26 (15)
15 July	1 (0)	48 (18)	0 (1)	25 (0)	0 (3)	74 (22)
25 July	0 (0)	61 (2)	16 (0)	67 (51)	0 (4)	144 (57)
5/6 August	0 (0)	1 (12)	0 (0)	2 (0)	0 (8)	3 (20)
15 August	0 (0)	13 (37)	0 (0)	5 (2)	1 (0)	19 (39)
25 August	0 (1)	0 (4)	1 (1)	2 (0)	1 (1)	4 (7)
5 September	0 (0)	66 (121)	0 (0)	9 (5)	1 (1)	76 (127)
15 September	1 (0)	93 (61)	0 (0)	1 (3)	1 (0)	96 (64)
23 September	0 (0)	238 (16)	1 (0)	18 (9)	1 (0)	258 (25)

*Transects 1 and 3 were surveyed on 29 July 1977; Transects 2, 4 and 5 were surveyed on 28 July 1977.

[+] Parentheses enclose the number of glaucous gulls recorded 'off-transect' (>200 m from either side of the aircraft). Numbers to the left of the parentheses are birds seen on-transect.

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1 September 1977 (451 birds; see Table 36), based on the surveys of barrier island beach transects, was remarkably similar to the number recorded on and off-transect during the 30 August 1977 aerial survey (421 birds, see Table 43). The shoreline surveys indicated that most gulls were along the seaward beaches of the islands.

The estimated total number of glaucous gulls present along the barrier islands on 14 September 1977, during the final beach survey was 58 birds (Table 38). This number represented a substantial decrease from numbers observed and estimated for 30 August and 1 September 1977.

During the period 18-20 September 1977, the ponds and lakes on the mainland tundra of the North Slope froze over and no open water was available to gulls at inland locations. Consequently, the estimated and observed numbers of glaucous gulls (and oldsquaws, see earlier discussion) present in the study area were higher during the 22 September 1977 aerial survey than on any other date during 1977 (or during the entire study). In view of the low numbers of glaucous gulls present during the 14 September beach survey (Table 38), this increase apparently occurred between 14 and 22 September. Of the 3097 glaucous gulls observed on 22 September 1977, approximately 92% (2857 birds) were along the barrier islands (Transect 2; Table 43). This number represents a density of 193.0 glaucous gulls/km^2--the highest density of this species recorded during the entire study. On this date 240 glaucous gulls (13.5 birds/km^2) were recorded along the mainland shoreline.

In 1978, the number of glaucous gulls recorded on-transect in shoreline habitats, along both barrier islands and the mainland shoreline, increased to a peak of 128 birds (5.0 birds/km^2) on 25 July. Thereafter the number of glaucous gulls on-transect in all lagoon habitats did not exceed 18 birds (0.46 birds/km^2; 15 August 1978; Table 38) until the 5 September aerial survey when 66 birds (4.5 birds/km^2) were recorded along the barrier island transect (Table 43). Two days earlier (3 September) a density of 5.4 glaucous gulls/km was recorded on shoreline transects south of the barrier islands; this density extrapolated to an estimated total of 185 gulls present along the entire length of the lagoonside beaches of the Jones Islands (Table 38). During 1978, the final shoreline surveys were conducted on 3 September. However, during the last two aerial surveys, on

15 and 23 September, the number of glaucous gulls present along lagoonside beaches of the barrier islands increased to the highest levels recorded in the study area during 1978; 93 birds (6.3 birds/km^2) and 238 birds (16.1 birds/km^2), respectively. This late-season increase of glaucous gulls along the barrier islands, although of lower amplitude, follows the same general trend in distribution and abundance observed during 1977 (Tables 36, 43 and 48). Very few glaucous gulls were recorded in areas away from the Jones Islands during these last two aerial surveys (see Table 43).

During the four aerial surveys conducted in barrier island-lagoon habitats in 1979, over 4000 glaucous gulls were recorded. Over 3200 of these gulls were seen along barrier island transects during the three-week period 31 August to 23 September. The late-season increase of glaucous gulls along the barrier islands occurred again in 1979, as it had during 1977 and 1978 (see Table 44).

The mean density of glaucous gulls present in the Simpson Lagoon study area during 1978 and 1979 was not significantly different from the densities at locations east and west of the study area (Tables 45 and 46; for 1978, Friedman $\chi_r^2=4.5$, $n=10$, $k=3$, $p>0.10$; for 1979, Friedman $\chi_r^2=0.00$, $n=10$, $k=3$, $p=1.00$).

No glaucous gulls were collected during 1978 or 1979; however, of the 27 collected in Simpson Lagoon during the 16 July to 19 September 1977 period, eight were adult males and one was a two-year old male. Eleven female glaucous gulls, of which nine were adults, two were one-year-old birds and five were juveniles, were also collected.

Discussion

As mentioned earlier, the term *staging*, as used in this report, refers to any large and dense concentration of birds gathered during the spring through fall period at a specific location or in a specific habitat for any purpose other than nesting or molting. Staging may occur prior to, during or after migration and may involve courtship, copulation and/or feeding.

After brood-rearing at tundra locations, juveniles of certain species of shorebirds, such as red phalaropes, northern phalaropes, white-rumped sandpipers and semipalmated sandpipers, leave the tundra and concentrate

Table 44. Total numbers of glaucous gulls recorded in all habitats during aerial surveys of five transects in the Jones Islands-Simpson Lagoon area, 22 June to 23 September 1979.

Transect #	22 June	28/29 July	31 Aug.-1 Sept.	23 Sept.
1	0 (0)*	0 (0)	1 (0)	0 (0)
2	6 (2)	4 (3)	304 (9)	1191 (104)
3	0 (0)	0 (2)	0 (0)	0 (4)
4	1 (0)	5 (1)	21 (20)	6 (0)
5	0 (3)	0 (1)	63 (1)	7 (0)
Total	7 (5)	9 (7)	389 (30)	1204 (108)

*Parentheses enclose the number of gulls recorded 'off-transect' (>200 m from either side of the aircraft). Numbers to the left of parentheses are birds seen on-transect.

Table 45. Numbers of glaucous gulls recorded on- and off-transect along various sections of the Beaufort Sea coast of northeastern Alaska, June to September 1978.

	West of Simpson Lagoon*			Simpson Lagoon			East of Simpson Lagoon†		
		# Gulls			# Gulls			# Gulls	
Survey Date	# km² Surveyed	on	off	# km² Surveyed	on	off	# km² Surveyed	on	off
23 June	12.0	22	72	39.9	35	0	31.3	192	1
5 July	65.5	150	506	39.9	24	9	322.8	183	249
15 July	12.0	4	13	39.9	71	19	31.3	363	97
25 July	65.5	238	99	39.9	144	53	162.0	109	394
5 August	65.5	44	14	39.9	3	12	315.1	460	320
15 August	12.0	3	0	39.9	18	39	31.3	118	120
25 August	5.5	0	0	39.9	3	5	126.9	217	120
5/6 September	65.5	272	47	39.9	75	126	315.1	722	406
15 September	12.0	39	14	39.9	94	64	31.3	13	59
23 September	12.0	20	15	39.9	257	25	126.9	398	179
All Dates	327.5	792	730	399.2	926	352	1393.9	2775	1945
Mean Density		2.42			2.32			1.99	

*This area included as many as six transects (163.7 km x 0.4 km = 65.5 km²); it extended as far west as Atigaru Pt. and included most of the Colville River delta (see Figure 2A-B).

†This area included as many as 11 transects (787.8 km x 0.4 km = 315.1 km²); it extended as far east as the Canada-U.S. border and as far north as the Midway Islands, north of Prudhoe Bay (see Figure 2C-G).

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Table 46. Numbers of glaucous gulls recorded on- and off-transect along various sections of the Beaufort Sea coast of northeastern Alaska, June to September 1979.

	West of Simpson Lagoon*			Simpson Lagoon			East of Simpson Lagoon†		
		# Gulls			# Gulls			# Gulls	
Survey Date	# km^2 Surveyed	on	off	# km^2 Surveyed	on	off	# km^2 Surveyed	on	off
22 June	65.5	93	8	39.9	7	2	93.8	53	169
28/29 July	65.5	99	97	39.9	9	6	222.3	478	162
31 August	65.5	478	384	39.9	975	29	13.9	298	64
23 September	65.5	238	5	39.9	1197	108	31.3	81	75
All Dates	262.0	908	494	159.6	2188	145	361.3	910	470
Mean Density		3.47			13.7			2.52	

*This area included as many as six transects (163.7 km x 0.4 km = 65.5 km^2); it extended as far west as Atigaru Pt. and included most of the Colville River delta (see Figure 2A-B).

†This area included as many as 11 transects (787.8 km x 0.4 km = 315.1 km^2); it extended as far east as the Canada-U.S. border and as far north as the Midway Islands, north of Prudhoe Bay (see Figure 2C-G).

(stage) along coastlines (Parmelee et al. 1967). In Simpson Lagoon, juvenile phalaropes were the only shorebirds that gathered in sufficient numbers (10^3) to be considered a key species. The phalaropes have been treated as a single group throughout much of this study, even though differences in their biology no doubt occur.

The only other species of bird that was considered during this study to be a key species is the glaucous gull. During late September thousands of these birds congregated (staged) along the barrier islands to feed.

Phalaropes

In the Simpson Lagoon area, phalaropes did not use coastal areas as spring staging sites as reported in the Point Barrow area by Connors and Risebrough (1976, 1977, 1978). Phalaropes were not abundant in the Simpson Lagoon-Jones Islands study area until August, when juvenile birds left rearing areas on the mainland tundra and arrived along barrier island shorelines to feed. In mid August, during the peak of their abundance in the study area and coincident with peak abundance in the Point Barrow area (Connors and Risebrough 1976, 1977, 1978), phalaropes were abundant along all the shorelines in our study area.

Phalaropes are unique shorebirds in that while at sea or along the coast they feed from the neuston (surface layer of water) while swimming. In fact, a typical method of swimming while feeding ('spinning', see Palmer 1967:264) has been described by several investigators (Tinbergen 1935; Höhn 1971) as a means of moving invertebrate prey to the surface and within easy reach.

Connors and Risebrough (1977, 1978) have shown that during some years the presence of feeding juvenile phalaropes along particular beaches in the Point Barrow area was related to wind direction and possibly to food abundance; during other years, however, they found no such relationships.

During 1977 and 1978 we conducted our shorebird censuses so that we could examine the effects of wind on phalarope distribution. During 1977 we censused all of our shorebird transects on relatively calm days (winds <3 km/h from directions varying between 010° and 090°). During 1978, we censused our shorebird transects on a systematic basis (approximately every five days) with no regard to wind speed or direction.

In 1977 and 1978, 10 barrier island transects (five oceanside and five lagoonside) were censused for shorebirds on five and eight occasions, respectively. Phalaropes were present on the transects during 3 of the 5 surveys in 1977, and during 7 of 8 surveys in 1978. During the three surveys in 1977 the winds were relatively calm; during the seven surveys in 1978, the average wind speed was 16.2 ± 7.5 km/h (range=5.3 to 28.3 km/h) and the wind directions were primarily from northern and northeastern azimuths (range=320° to 089°; see Table 47).

During the four surveys in 1978 when wind speeds were greater than average, only 23.3% of the phalaropes (mean density=9.4 ± 17.0 birds/km) recorded along the barrier islands were present on the oceanside (exposed side) of the barrier islands; conversely, 76.7% (mean density=26.1 ± 22.8 birds/km) were on the lee sides. During surveys when wind speeds were less than average, almost two-thirds (65.9%) of the phalaropes (mean density= 27.8 ± 29.5 birds/km) were present along the oceanside beaches. This percent is lower than the 85.7% recorded on the exposed beaches during the three 1977 surveys, when winds were calm, but it is noteworthy that on the calm days in 1977 and on days in 1978 when wind speeds were less than average, well over half of all the feeding phalaropes were present along the oceanside (seaward) beaches of the barrier islands where they fed primarily on marine copepods, amphipods and other small marine invertebrates. The high densities of phalaropes along seaward beaches of the barrier islands may be related to an abundance of food organisms there, but we collected too few birds or invertebrate samples in those habitats to test this hypothesis (see Fig. 23).

The less specific analysis of the distribution of all shorebirds (including phalaropes) along the three beach types in the study area also indicated a significant preference for oceanside beaches, regardless of wind speed or direction. It is unclear whether wind and waves concentrate invertebrates along windward beaches, where birds may more easily pick them from the clear marine water or from the shoreline substrates; or whether specific prey items simply are more abundant in marine than in lagoon waters, and shorebirds concentrate along barrier island shorelines because of an abundance of food organisms there.

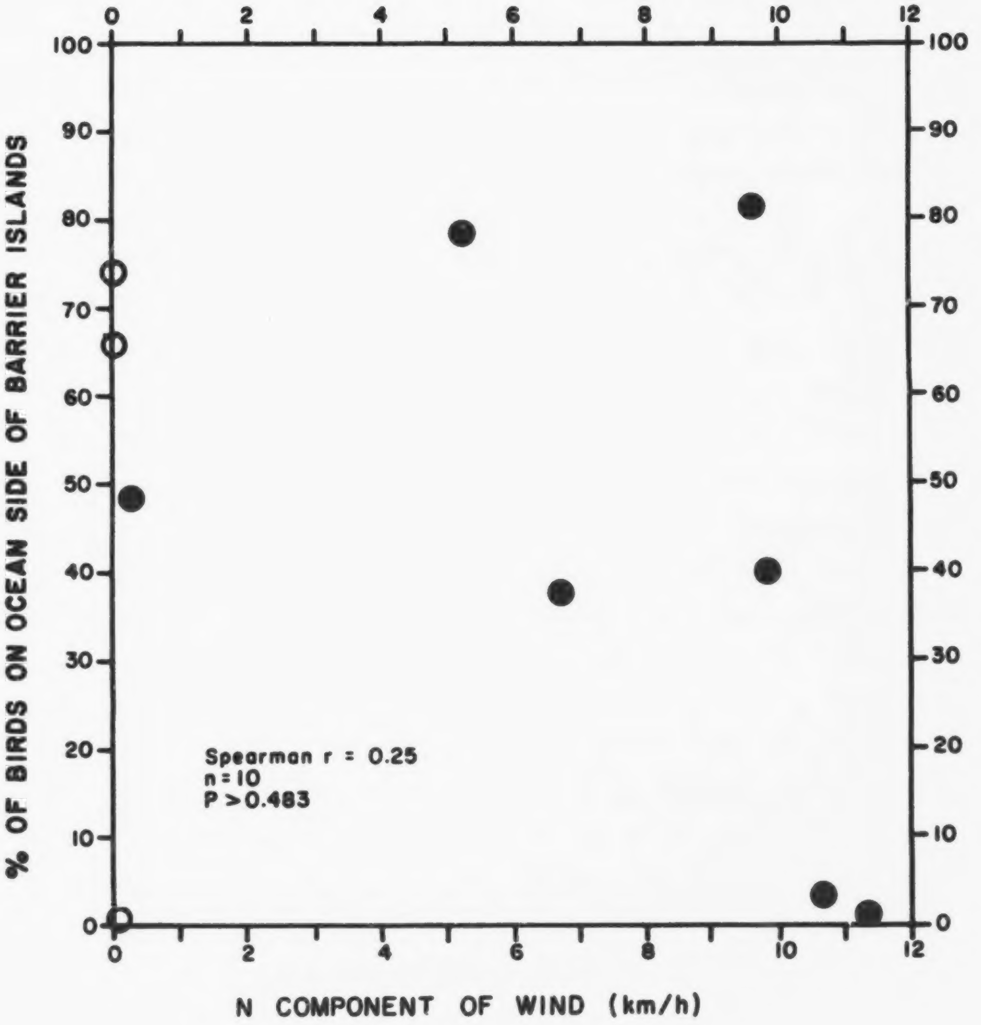

Figure 23. Relationship between wind direction and speed (N component of wind) and the position of feeding phalaropes near the Jones Islands, Alaska, during 1977 and 1978. N component of wind = (wind speed) cos (wind direction). ○ = 1977 data derived from Table 36 and ● = 1978 data derived from Table 47.

Table 47. Distribution of phalaropes in relation to wind speed and direction on Barrier Island beaches, 4 August to 3 September 1978.

	Barrier Island Oceanside Beach		Barrier Island Lagoonside Beach			
	# of Phalaropes		# of Phalaropes		Wind	
Date	Density (birds/km)	%	Density (birds/km)	%	Speed (km/hr)	Direction (°)
4 August	7.0	81.4	1.6	18.6	12.4	320
9 August	2.0	40.0	3.0	60.0	28.3	070
14 August	0.2	0.4	53.8	99.6	17.7	050
19 August	34.8	49.9	35.0	50.1	17.7	089
24 August	14.8	38.3	23.8	61.7	10.6	050
29 August	61.6	78.0	17.4	22.0	5.3	010
1 September	0.4	3.1	12.6	96.9	21.3	060
	17.3 ± 23.1*	41.6 ± 32.1	21.0 ± 18.6	58.4 ± 32.1	16.2 ± 7.5	

*Mean ± standard deviation.

Glaucous Gull

Early during the summers of 1977 and 1978, before the ice had moved out of Simpson Lagoon and away from the seaward shoreline of the barrier islands, small numbers of glaucous gulls were present in the study area; those seen at this time were mainly in exposed gravel areas along the barrier islands. During the first surveys conducted after the ice moved out of Simpson Lagoon (28 July 1977 and 15 July 1978) the largest proportions (approximately 97.5% and 94.8%, respectively) of the total number of glaucous gulls (158 and 96 birds) recorded in the study area were seen along the barrier islands and mainland shorelines (Transects 2 and 4; Table 43). During early spring in the Beaufort Sea, anadromous fish species such as cisco, whitefish and arctic char leave their wintering areas in freshwater streams and rivers and, as soon as a sufficient amount of water is available, begin a migration along the coast (Craig and McCart 1976; Craig and Haldorson, Ecology of Fish, this volume). The presence of glaucous gulls along the mainland and barrier island shorelines during the period just after lagoon breakup (breakup was complete on 11 July 1977 and 6 July 1978) may be related to the presence of migrating fish in this area. Fish appeared in the diet of glaucous gulls sporadically throughout 1977 (the only season when glaucous gull stomachs were sampled) but the largest quantity recorded in an individual gull stomach was from a bird collected at a barrier island location relatively early in the season (16 July 1977).

The consistent presence and build-up of glaucous gulls along the beaches of the barrier islands throughout the open-water season is probably related to the extensive feeding habitat available there. The importance of barrier island habitats to glaucous gulls is significant--of the total 6694 birds recorded on- and off-transect in Simpson Lagoon and along the Jones Islands during the three summers of aerial surveys, approximately 90% (6022) were recorded on or adjacent to the single barrier island transect (Transect 2).

Ingolfsson (1967) showed that in Iceland, the glaucous gull is more closely associated with intertidal or shoreline habitats than were four other species of large arctic gulls. Barrier islands provide both seaward and lagoonward shoreline feeding habitats. Furthermore, the presence of marine and lagoon habitats in close proximity along the barrier islands provides a quantity and diversity of food organisms not present along the mainland shorelines (see Griffiths and Craig 1978, Appendix Table I).

Arctic Tern and Sabine's Gull

In general, arctic terns have left the Beaufort Sea area by early September (Johnson et al. 1975). During their fall migration in 1977, adult and juvenile arctic terns, with smaller numbers of adult and juvenile Sabine's gulls, were observed concentrated at specific locations in Simpson Lagoon during the third week in August. These concentrations in 1977 occurred approximately two weeks later than concentrations farther west on the Plover Islands, during 1976. These several thousand arctic terns were present from the first week of August to early September (Divoky 1978a:490). Connors and Risebrough (1977) also found that arctic terns and Sabine's gulls were abundant in the Point Barrow area during the second week of August 1976, and several other workers have mentioned the abundance of Sabine's gulls at Point Barrow in late summer (see 'MIGRATION' section).

Presumably these species rely at least partly upon pre-migration feeding to accumulate fat reserves used during their long southward migrations; locations along the barrier islands where gulls and terns concentrate to feed may, therefore, be important to these species.

FEEDING ECOLOGY

Results

Oldsquaw

As mentioned in the methods, oldsquaws were collected differently in 1977 and 1978. Although we collected birds systematically during 1977, we did so relatively indiscriminantly, with only brief attention given to whether birds or flocks appeared to be feeding (about 3-5 min of observation prior to each collection). During 1978, approximately half of our sample of oldsquaw collections (25 of 45 collections, 81 of 108 birds) were of birds or flocks that were observed for a longer period of time than in 1977 (about 10-30 min) and that were determined to be feeding. Of the 81 feeding birds that we collected in 1978, 80% had identifiable food in their guts. Of the 27 birds that were indiscriminantly shot (no prior observations of behavior conducted) only 26% had some identifiable food in their guts.

During 1977, 64% (58 birds) of the total oldsquaws collected had identifiable food in their guts; that proportion was similar to the overall value for the 1978 collections (67%). It is apparent, then, that optimum use of oldsquaw specimens is dependent on at least some observation of the birds prior to collection in order to ensure that a reasonable proportion has been feeding and will be useful in prey analyses.

Although we earlier presented the results of oldsquaw feeding ecology studies on a seasonal basis (see Johnson 1978; early, mid and late season diets of oldsquaws), the results of subsequent analyses (Cluster Analyses, Clifford and Stephenson, 1975:134) of the data indicated no justification for such a categorization. Therefore we have presented all subsequent results (Johnson 1979a and this report) on the basis of their total season diets.

Of the 91 oldsquaws collected as part of the feeding ecology investigations during 1977, 15 had empty stomachs and 18 had only unidentifiable material present in their stomachs. Four birds were accidentally captured in gill nets and may have regurgitated some food while drowning; these birds were omitted from the stomach analyses. The average diet of the remaining 54 birds included, on a percent estimated volume basis, 58.7% mysids and 14.2% amphipods (Table 48). The remaining portions of the diet of oldsquaws during 1977 consisted primarily of bivalves (8.1%), isopods (2.3%), small fishes (2.3%), and a relatively large proportion of unidentifiable material (14.2%) (Table 48).

The results of the oldsquaw feeding ecology studies conducted in Simpson Lagoon during 1978 were similar to 1977 results (Morisita Similarity Index; C=0.74; Horn 1966). Of the 108 oldsquaws collected during 1978, 34 had empty stomachs and two had only unidentifiable material present in their stomachs. The average diet of the remaining 72 birds included, on a percent estimated volume basis, 68.5% mysids and 15.5% amphipods (Table 48). The remaining portions of the oldsquaw diet during 1978 consisted primarily of bivalves (12.1%). Unlike the 1977 oldsquaw diet, the proportion of the 1978 diet that was comprised of unidentifiable material (1.5%) was small (Table 48).

Griffiths and Dillinger (Ecology of Invertebrates, this volume) discuss the limitations and biases associated with conventional equipment and procedures used in sampling marine zooplankton and epibenthic animals. Epibenthic invertebrates of the types important to oldsquaws are especially difficult to sample quantitatively. Methods used to sample such animals in 1978 were much improved over those used during 1977. These problems should be considered when interpreting the data concerning food availability.

During 1977, few mysids or amphipods were collected from the surface-waters of the lagoon (see Fig. 24). This evidence, plus our observations and those of others (Peterson 1976) of the diving behavior of oldsquaws, indicated that oldsquaws probably rarely feed in this layer. The predominant invertebrate taxa present in the surface layer during 1977 were, on an estimated percent of total volume basis, copepods (68.1%) and cnidarians (16.7%). Small proportions of amphipods (5.7%) and chaetognaths (3.3%) comprised most of the remainder of the organisms collected in this habitat (see Fig. 24).

Copepods also represented almost two-thirds (64.4%) of the total volume of invertebrate organisms present in the mid-water habitat samples collected during 1977 (see Fig. 24); this proportion of copepods was similar to that found in the surface water samples. Mysids and amphipods both

Table 48. A comparison of food organisms consumed by oldsquaws throughout the season at Simpson Lagoon, Alaska, during 1977 and 1978.

	1977 (n=54; total points=443*)		1978 (n=72; total points=422)	
Taxa	% Total	% Total Identifiable	% Total	% Total Identifiable
Mysids	58.7	68.4	68.5	69.5
Amphipods	14.2	16.6	15.5	15.7
Bivalves	8.1	9.5	12.1	12.3
Isopods	2.3	2.6	1.0	1.0
Fish	2.3	2.6	0.2	0.2
Copepods	0.1	0.1	0.2	0.2
Polychaetes	0	0	0.7	0.7
Euphausiids	0	0	0.2	0.2
Priapulids	0	0	0.1	0.1
Tunicates	0	0	0.1	0.1
Unidentifiable	14.2	-	1.5	-
TOTAL	99.9	99.8	100.1	100.0

*See Griffiths et al. (1975) for a description of the points method for assessing the relative importance of food organisms.

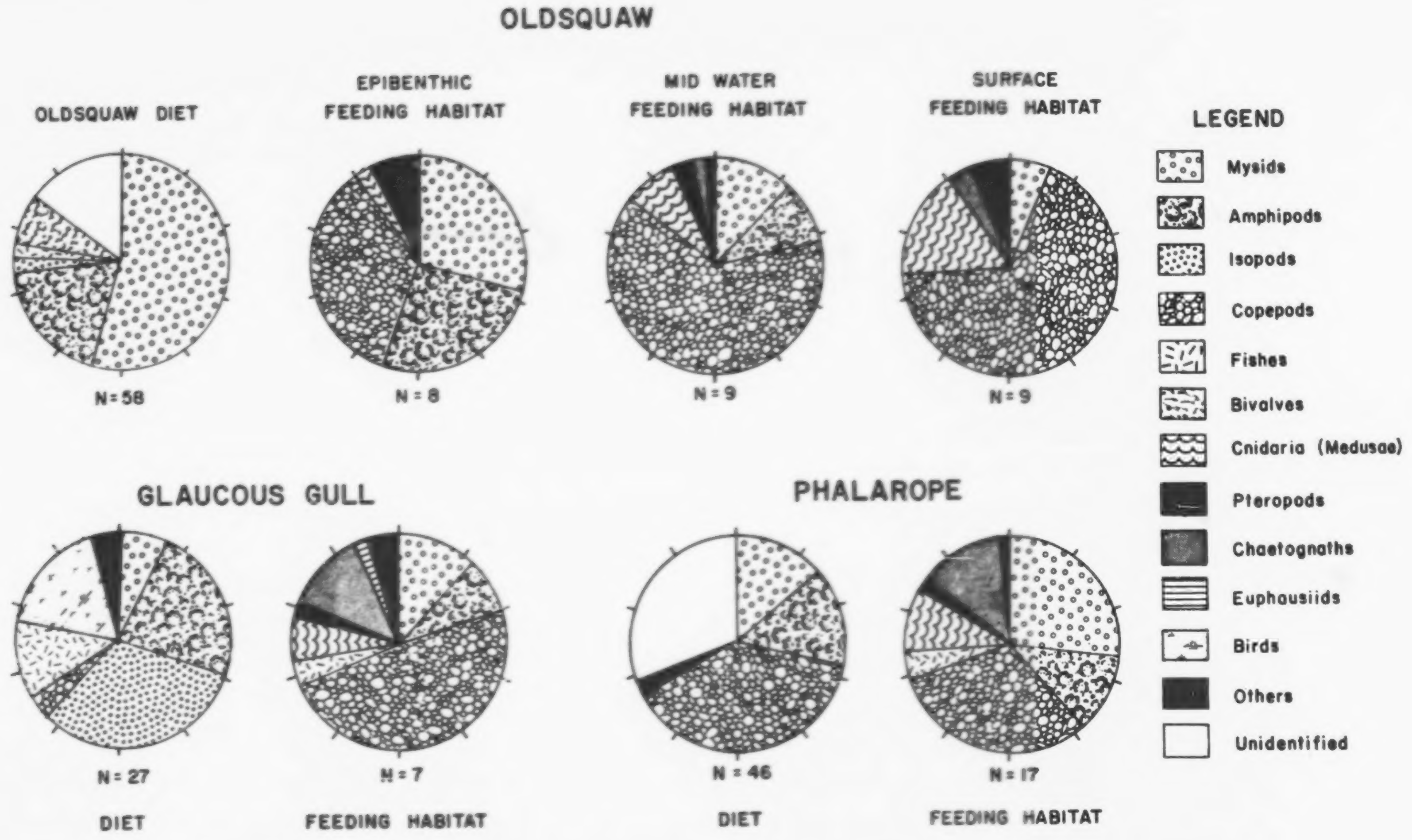

Figure 24. A comparison of the organisms present in the diets of oldsquaws, phalaropes, glaucous gulls and the organisms present in their feeding habitats during 1977. All proportions are expressed as approximate 'percent volumes' (based on the Hynes point method).

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comprised larger proportions (11.7 and 9.4%, respectively) of the mid-water samples than of the surface samples. Cnidarians, chaetognaths and ctenophores comprised the major proportion of the remainder of the mid-water samples during 1977.

Copepods, mysids and amphipods comprised the major proportions (33.8, 28.1 and 27.5%, respectively) of the epibenthic samples collected during 1977 (Table 49). Observations by a SCUBA diver at several locations in Simpson Lagoon during 1977 and 1978, including a series of dives where flocks of oldsquaws had been feeding, indicated that mysids and amphipods were the most conspicuous invertebrate organisms present in the epibenthos (Griffiths and Craig 1978; Griffiths and Dillinger 1979, this volume).

Because both mysids and amphipods, the organisms that comprised the major proportions of the diet of oldsquaws during 1977, were proportionately most abundant in the lagoon epibenthos, it is probable that oldsquaws fed almost exclusively from this habitat rather than from either the surface or the mid-water layers, where mysids and amphipods were relatively uncommon. Copepods are extremely small, and although they comprised one-third of the volume of samples collected from the epibenthos during 1977*, they were not observed by the divers during that year in the epibenthos. Possibly for the same reason (small and difficult to detect by feeding oldsquaws) copepods did not comprise a significant proportion of the diet of oldsquaws during 1977 (see Table 48 and Fig. 24). The very small proportion of copepods in the diet during 1977 may have been taken incidentally during the process of feeding on other epibenthic invertebrates.

Studies conducted during 1977 indicated that oldsquaws were feeding primarily from the epibenthos; samples for analyses of food availability were, therefore, collected only from this region of the lagoon during 1978. Gear used to sample the epibenthos (see 'Methods' section) during 1977 and 1978 were different; therefore, comparisons of the data from these two years should be made with caution.

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*The device used to sample the epibenthos during 1977 was a small ($0.25\ m^2$) circular plankton net. This net sampled while being lowered to and retrieved from the epibenthos, and therefore may have collected some copepods from the surface and mid-water layers of the lagoon.

Table 49. A comparison of oldsquaw total season diet and the composition of oldsquaw epibenthic feeding habitat samples in the Jones Islands-Simpson Lagoon area of Alaska during 1977 and 1978.

Taxon	1977 Oldsquaw Diet (n = 54; total points* = 443) % Total	1977 Epibenthic Habitat Samples (n = 8; total points = 160) % Total	1978 Oldsquaw Diet (n = 72; total points = 422) % Total	1978 Epibenthic Habitat Samples (n = 39; total points = 166½) % Total
Mysids	58.7	28.1	68.5	48.9
Amphipods	14.2	27.5	15.5	36.6
Bivalves	8.1	1.9	12.1	7.1
Isopods	2.3	0	1.0	1.4
Fishes	2.3	0	0.2	0.3
Copepods	0.1	33.8	0.2	0.5
Polychaetes	0	1.9	0.7	2.4
Euphausiids	0	0	0.2	0
Priapulids	0	0	0.1	1.1
Tunicates	0	0	0.1	0.6
Cnidarians	0	2.5	0	0.8
Pteropods	0	3.1	0	0
Ostracods	0	0.6	0	0
Foraminiferans	0	0.6	0	0
Sponges	0	0	0	0.1
Chaetognaths	0	0	0	0.1
Cumaceans	0	0	0	0.1
Unidentifiable	14.2	0	1.5	0
TOTAL	99.9	100.0	100.1	100.0

*See Griffiths et al. (1975) for a description of the points method for assessing the relative importance of food organisms.

During 1978 the relative abundance and importance of the invertebrate taxa present in the epibenthos when and where feeding oldsquaws were collected was more similar to that found in oldsquaw stomachs than was the case during 1977 (Table 49). Probably because more effective sampling gear was used during 1978, the apparent importance of copepods in the epibenthos was markedly lower in 1978 (0.5% of estimated volume) than in 1977 (33.8%). The specific prey of oldsquaws during the summer of 1978 are given in Table 50.

Mysids and amphipods collectively comprised 85.5% of the estimated volume of invertebrates in the 1978 epibenthos samples. Although the drop net sampling technique (see Griffiths and Dillinger 1979) was not an adequate infaunal sampler, a notably larger proportion of the volume of samples consisted of bivalves in 1978 (7.1%) than in 1977 (1.9%). Table 49 gives a comparison for both 1977 and 1978 of the major taxa present in the stomachs of oldsquaws and in the corresponding epibenthic feeding habitat samples in Simpson Lagoon. The results from 1978, when more effective epibenthic sampling gear was used, show the close relationship between the relative volumes of major invertebrate taxa in oldsquaw stomachs and in feeding habitats. In both 1977 and 1978, the relative proportions of mysids found in oldsquaw stomachs were approximately twice those found in feeding habitats. Similarly, during both 1977 and 1978, the proportions of amphipods in oldsquaw stomachs were about half those found in feeding habitats.

Other evidence that oldsquaws may feed selectively is given by Rofritz (1977) for oldsquaws feeding in Milwaukee Harbor, Lake Michigan. Rofritz found that during January of 1972, oldsquaws fed almost exclusively on oligochaetes, even though molluscs and crustaceans were also present in the benthos were oldsquaws were feeding. Rofritz suggested that oldsquaws in Milwaukee Harbor may have selected oligochaetes as a food source because oligochaetes had a significantly higher caloric value per gram of body weight than did other benthic fauna present.

When stomach contents of oldsquaws collected at one place and time in Simpson Lagoon were compared with food availability in the epibenthos at that same place and time, a positive and highly significant correlation was found (Fig. 25). A very similar relationship was reported by

Table 50. Prey* consumed by oldsquaws and phalaropes in Simpson Lagoon during 1977 and 1978.

	1977		1978	
Prey	Oldsquaws (n=54)	Phalaropes (n=46)**	Oldsquaws (n=72)	Phalaropes (n=46)
Mysis litoralis	34.1	8.1	70.8	2.3
Mysis relicta	33.5	8.1	8.9	-
Apherusa glacialis	< 0.1	8.1	-	6.7
Onisimus glacialis	8.0	8.1	10.4	82.4
Gammarus setosus	1.7	20.2	0.8	-
Parathemisto spp.	4.9	20.2	0.3	-
Pontoporeia affinis	-	20.2	0.1	-
Pontporeia femorata	-	20.2	< 0.1	-
Gammaricanthus loricatus	1.2	20.2	0.7	6.7
Copepod	1.2	65.3	< 0.1	-
Isopod	2.7	-	0.9	1.9
Cumacean	-	-	0.1	-
Euphausiid	-	0.6	0.1	-
Fish	2.7	-	0.4	-
Bivalves	9.6	-	6.2	-
Polychaetes	-	-	< 0.1	-
Pteropods	-	4.0	-	-
Others	-	1.8	0.3	-
Total	99.7	100.0	100.3	100.0

*Presented as % composition (wet weight). Unidentified fractions of the samples have been assigned to the various prey categories using the assumption that they would appear there in the same proportions that they do in the identified fractions.

**Detailed laboratory analyses of phalarope prey were not conducted during 1977; these values represent wet weight determination of major taxonomic groups.

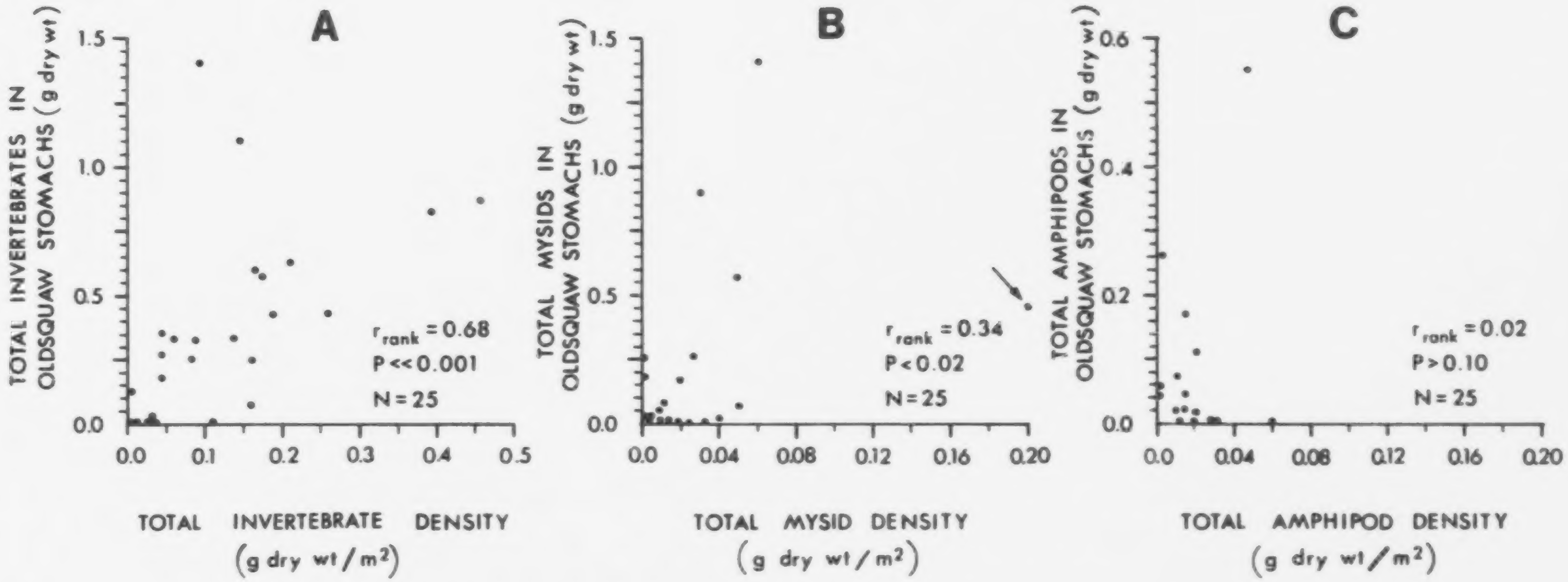

Figure 25. The relationship between the density of invertebrates in oldsquaw feeding habitats and the amount of invertebrates consumed by oldsquaws in Simpson Lagoon, Alaska. Each point represents one or more oldsquaws collected at one place and time.

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Peterson and Ellarson (1977). Although they provided no data, they found that in Lake Michigan, oldsquaw (and the commercially important whitefish) concentrated to feed in the same areas where the epibenthic amphipod *Pontoporeia affinis* reached maximum density.

Data from both 1977 and 1978 indicate that, on the basis of the total season diet, the mean sizes of mysids and amphipods consumed by oldsquaws were significantly larger than the mean sizes of the same species found in oldsquaw feeding habitat samples (see Table 51 and Fig. 26). In 1978, the mean lengths of *Mysis litoralis*, *M. relicta* and *O. glacialis* in oldsquaw stomachs were all significantly greater than the mean lengths of these taxa in corresponding habitat samples (Wilcoxon matched-pairs tests; $P<0.01$; $P<0.02$ and $P<0.01$, respectively). Hence, in Simpson Lagoon feeding oldsquaws apparently tended to select larger individuals of at least the most common prey species (mysids and amphipods) found in epibenthic feeding habitats (see Fig. 26). This selection by oldsquaws of the large size classes of invertebrates is most apparent during mid-July for all major prey consumed, and is less apparent later in the season, especially for *Mysis litoralis* (Table 52).

During 1978, a major effort was made to conduct detailed laboratory analyses of the invertebrates consumed by oldsquaws and found in their feeding habitat samples (see Griffiths and Dillinger 1979). Table 53 gives a comparison of the proportions of these major taxa found in oldsquaw stomachs as determined by precise measurements of wet weight, ash-free dry weight, energy content (kilocalories) and abundance (total numbers of individuals) as well as the less precise and more qualitative modified Hynes Point method (Hynes 1950; Griffiths et al. 1975). This comparison suggests that the qualitative Hynes Point method used in both 1977 and 1978, when compared with the more precise and quantitative approaches to stomach analyses, was a relatively accurate indicator of the proportions and importances of various major taxa of prey organisms consumed.

Phalaropes

Of the 83 red and northern phalaropes collected in the study area during the 3 to 24 August 1977 period, 62 birds had food organisms in their stomachs when they were collected. Almost one-third (30%) of their

Table 51. A comparison of the sizes of three important marine invertebrates taken from oldsquaw stomachs and taken from lagoon epibenthic habitat samples collected during 1977 in Simpson Lagoon, Alaska.*

Taxon	Oldsquaw Stomach (length mm)	Epibenthic Sample (length mm)	z**	P
Onisimus glacialis	5.64 ± 1.16[†]	4.38 ± 1.68	2.35	<0.009
Apherusa glacialis	9.33 ± 1.67	6.03 ± 1.67	3.66	<<0.001
Mysis litoralis	13.28 ± 2.59	10.74 ± 3.42	1.97	<0.03

*Habitat samples were collected at the locations where birds were collected.

[†] Mean ± standard deviation.

**Wilcoxon matched-pairs test; n_1 and n_2 = 20 organisms of each species selected randomly from both the oldsquaw stomachs and the associated epibenthic samples.

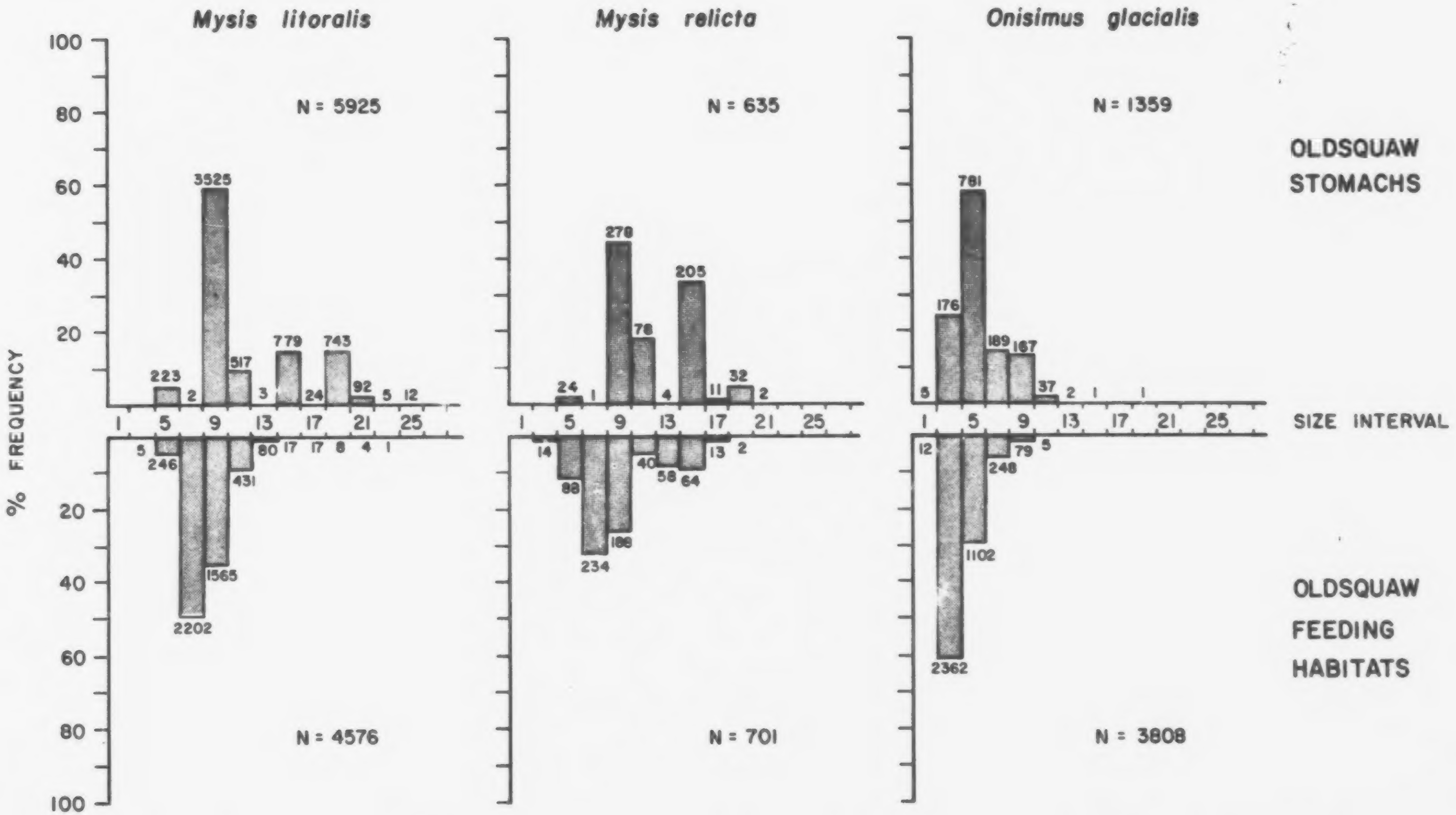

Figure 26. A comparison of the distributions of sizes of the three most important invertebrate prey species consumed by oldsquaws and found in oldsquaw feeding habitats. This analysis is based on a comparison between 79 oldsquaw stomachs and 136 associated habitat samples, representing 39 collections made in Simpson Lagoon during the period 10 July to 23 September 1978.

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Table 52. Comparison of prey sizes available and prey sizes eaten by oldsquaws in Simpson Lagoon during 1978.*

Prey Species	Overlap Index** for Various Sampling Periods			
	Mid July n=8-14	Early August n=5-12	Mid August n=5-13	Late August n=10-13
Mysis litoralis	0.12	0.90	0.82	0.83
Mysis relicta	0.21	0.64	0.85	0.71
Onisimus glacialis	0.37	0.65	0.75	0.82

*From Craig and Haldorson (this volume).

**Morisita Overlap Index (Horn 1966).

Table 53. The diet of oldsquaws in Simpson Lagoon during 1978 as determined by estimated relative volume, abundance, wet weight biomass, dry weight biomass and energy content.

	Volume		Abundance		Wet Weight		Ash-free Dry Weight		Energy Content	
Taxa	Points*	%	#	%	g	%	g	%	kcal	%
Mysids	289	68.5	6464	75.0	155.1	77.4	17.9	69.7	97.5	69.8
Amphipods	65 ¼	15.5	1845	21.4	23.7	11.8	4.2	16.3	21.3	15.3
Bivalves	51 ¼	12.1	260	3.0	13.3	6.6	2.6	10.1	14.7	10.5
Other Taxa	16 ½	3.9	48	0.6	8.3	4.1	1.0	3.9	6.1	4.4
Total	422	100.0	8617	100.0	200.4	99.9	25.7	100.0	139.6	100.0

*See Griffiths et al. (1975) for a description of the points method for assessing the relative importance of food organisms. Points listed in this table are only those of identifiable taxa; the unidentified portions of stomach contents are presumed to be comprised of remnants of organisms of the same taxa and present in the same proportions as those in the identified portions of stomach contents.

stomach contents was unidentifiable material. The major components of the identifiable portion were copepods (40%), amphipods (14.0%) and mysids (14.0%; Table 54). The remainder of the diet was comprised of very small amounts of fish (striated muscle), and small amounts of pteropods and insects.

Organisms collected from phalarope feeding habitats during 1977 were in proportions similar to those found in phalarope stomachs (Table 54). Copepods comprised the largest proportion (31.1%), with mysids (26.1%) and amphipods (12.1%) also present in significant proportions. These data suggest that when phalaropes fed along lagoon shorelines during 1977, they consumed small organisms in approximately the same proportions in which they were present. The apparent absence of cnidarians from stomachs was probably artifactual; these animals are very fragile, and phalaropes were observed to feed upon them (Johnson 1978). Similarly, chaetognaths comprised an estimated 12.9% of the food volume available in feeding habitats during 1977, but were not identified in the phalarope stomachs collected that year.

Of the 59 red and northern phalaropes collected in the Simpson Lagoon study area during the 6 August to 3 September 1978 period, 27 had food organisms in their stomachs. Unlike 1977, only a small proportion of the diet during 1978 was comprised of unidentifiable material (2.3% vs 30.0%). Almost three-fourths (72.6%) of the 1978 diet of phalaropes was comprised of amphipods, even though mysids represented a much larger proportion of the organisms (on a volume basis) in the habitat samples (Table 54). This result is quite different from that in 1977 when copepods represented slightly over 40% of the diet of phalaropes and represented 31.1% of the estimated volume of the organisms in phalarope feeding habitat samples (Table 54). In 1978, copepods represented only 12.3% of the food available.

Hence, during 1977, phalaropes fed on organisms approximately in the same proportions as the organisms occurred along the shorelines where these birds fed; copepods were the most important and the most available prey. During 1978, however, phalaropes preyed selectively on small amphipods and copepods, both of which were approximately five times less abundant than mysids, which represented a very small proportion of the phalarope diet (Table 54).

Table 54. A comparison of phalarope* total season diet and the composition of phalarope feeding habitat samples in the Jones Islands-Simpson Lagoon area of Alaska during 1977 and 1978.

	1977		1978	
	Phalarope Diet (n=46; points** = 269¾)	Feeding Habitat Samples (n=17: points = 140)	Phalarope Diet (n=26; points = 197¾)	Feeding Habitat Samples (n=30; points = 111¾)
Taxon	%	%	%	%
Copepod	40.2	31.1	22.6	12.3
Amphipod	14.0	12.1	72.6	13.9
Mysid	14.0	26.1	2.5	71.8
Chaetognaths	0.0	12.9	0.0	0.9
Euphausiids	0.2	1.1	0.0	0.4
Cnidaria	0.0	10.0	0.0	0.0
Fish	0.0	4.3	0.0	0.7
Pteropods	0.7	2.1	0.0	0.0
Decapod	0.0	0.4	0.0	0.0
Branchiopods	0.2	0.0	0.0	0.0
Insect	0.6	0.0	0.0	0.0
Unidentifiable	30.0	0.0	2.3	0.0
Total	99.9	100.1	100.0	100.0

*Northern phalarope and red phalarope have been treated as a single group.

**See Griffiths et al. (1975) for a description of the points method for assessing the relative importance of food organisms.

Comparisons of the diets of major bird and fish species collected during 1977 showed that the diet of northern phalaropes was most similar to that of arctic char (0.78), least cisco (0.74) and red phalaropes (0.74; Craig and Griffiths 1978). During 1977 the diet of red phalaropes was most similar to that of northern phalaropes (0.74) and fourhorn sculpins (0.57). During 1978, the collective diet of both phalaropes was most similar to that of the arctic cisco (Craig and Haldorson, Ecology of Fish, this volume).

Glaucous Gull

The glaucous gull was initially considered a key species and a small sample was collected during 1977; however, no glaucous gulls were collected during 1978. Of the 28 glaucous gulls collected during the 16 July to 19 September 1977 period, all but one was collected along the shoreline of a barrier island or the mainland; the one glaucous gull collected at a mid-lagoon location had an empty stomach. The diets of the remaining 27 glaucous gulls consisted largely of isopods (33.4% of the volume), amphipods (22.8%), small birds (a northern phalarope, 18.1%) and small fish (11.7%) (Table 55). Mysids and copepods comprised smaller proportions of the diet of glaucous gulls (6.7% and 3.1%, respectively). Euphausiids, bivalves, tunicates, hydroids and unidentifiable materials, all in small proportions, comprised the remainder of the diet. The diverse nature of the diet of this species, which included organisms ranging in size from small copepods and mysids to larger organisms such as isopods, small fish and small birds, suggests that glaucous gulls feed opportunistically along shorelines in the lagoons.

The relative proportions of invertebrates collected in shallow waters along shorelines where the glaucous gulls were feeding bore little resemblance to the relative proportions of invertebrates in the glaucous gull stomachs (Table 55). The most conspicuous invertebrates where glaucous gulls fed were copepods (48.6%), chaetognaths (12.5%), mysids (11.8%), amphipods (8.2%) and cnidarians (6.8%). Isopods, which comprised 33.4% of the total diet of glaucous gulls, represented only 0.2% of the available food.

Table 55. A comparison of the organisms found in the stomachs and in the feeding habitat sample of glaucous gulls in the Simpson Lagoon area of Alaska, 16 July to 19 September 1977.

Taxon	% Total Contents of Stomach (n=27; points=193*)	% Total Contents of Habitat Samples (n=7; points=140)
Mysids	6.7	11.8
Amphipods	22.8	8.2
Isopods	33.4	0.2
Copepods	3.1	48.6
Bivalves	0.5	0.0
Fish	11.7	3.6
Cnidaria (Medusae)	0	6.8
Pteropods	0	2.1
Chaetognaths	0	12.5
Euphausiids	1.0	2.0
Decapod Larvae	0	0.2
Tunicates	0.5	0.0
Tunicate Larvae	0	0.5
Hydroids	0.3	0
Larvaceans	0	0.2
Cumacean	0	0.9
Oligochaete	0	0.7
Ctenophore	0	1.3
Birds **	18.1	0
Unidentified	1.8	0
TOTAL	99.9	100.1

*See Griffiths et al. 1975 for a description of the points method of assessing the relative importance of food organisms.

**The stomach of one gull collected on 31 July 1977 contained half of a large coracoid bone (possibly chicken bone). The stomach of one other gull contained a juvenile northern phalarope that may have been injured during one of our earlier collection trips.

The analysis of dietary overlap in glaucous gulls and the key fish and other bird species found in Simpson Lagoon (Craig and Griffiths 1978) indicated that the diet of glaucous gulls was most similar to that of the least cisco and arctic char (0.64).

Discussion

Oldsquaw Feeding Ecology

Oldsquaws in Simpson Lagoon, as in Lake Michigan and at other locations, are largely opportunistic feeders. That is, they prey on those organisms most available to them. Ellarson (1956:215) and Hull (1914) recorded oldsquaws feeding on locally abundant minnows, and Madsen (1954) reported that bivalves comprised a major portion of the diet of oldsquaws collected off the coast of Denmark, where those molluscs were very abundant in the marine waters. Cottam (1939), Pehrsson (1974) and Bengtson (1971) showed that the abundant crustacea comprise a major proportion of the diet of oldsquaws in freshwater habitats. Lagler and Wienert (1948) also reported crustaceans and molluscs to be important prey of oldsquaws in Lake Michigan. In northern Sweden, Pehrsson (1974) found that both female oldsquaws with broods and other postbreeding oldsquaws selected and were concentrated on lakes that supported high densities of emphyllopod crustaceans. Gjosaeter and Saetre (1974) reported oldsquaws (and eiders) feeding extensively on the eggs of capelin (*Mallotus villosus*) during the spawning season of this fish in the Barents Sea.

The diet of oldsquaws in coastal wintering areas in North America (Stott and Olson 1973; Vermeer and Levings 1977; Sanger et al. 1979) and in Europe (Bagge et al. 1973; Nilsson 1972) similarly show that oldsquaws feed extensively on those organisms most abundant, primarily epibenthic crustaceans and molluscs.

In Simpson Lagoon, the principal prey of the key vertebrate predators, birds and fish, consisted of two species of mysids, six of amphipods, as well as two bivalves, several copepods, several isopods and various fish. As Craig and Haldorson (Ecology of Fish, this volume) have pointed out, this low diversity of principal prey eaten is reflected in the high degree of dietary overlap among the predators. Table 56 shows the similarity of

Table 56. Degree of similarity* of invertebrate prey consumed by birds and fish in Simpson Lagoon during 1977 and 1978.

	Arctic Cisco	Least Cisco	Arctic Char	Fourhorn Sculpin	Arctic Cod	Phalaropes	Oldsquaw
Oldsquaw	0.82 (0.90)**	0.84 (0.68)	0.29 (0.97)	0.30 (-)	0.72 (0.32)	- (0.06)	-
Phalaropes	- (0.12)	- (0.43)	- (0.06)	- (-)	- (0.17)	-	- (0.06)
Glaucous Gull	0.30 -	0.64 (-)	0.64 (-)	0.25 (-)	0.18 (-)	0.39 (-)	0.31 (-)

*From Craig and Haldorson (this volume) and Craig and Griffiths (1978); based on the Morisita index of Horn (1966).

**Values in parentheses are for 1978, those to the left are for 1977.

the prey consumed by key bird and fish species present in Simpson Lagoon during 1977 and 1978. Bengtson (1971) reported that five species of subarctic nesting diving ducks (including oldsquaws) in Lake Myvatn, Iceland, similarly showed a high degree of overlap in the prey they consumed; the total number of prey types consumed there was small also, and oldsquaws consumed primarily crustaceans (Cladocera).

The majority of oldsquaw prey, especially the two mysids and *Onisimus glacialis*, are epibenthic dwelling crustaceans. In many of the lagoons along the Beaufort coast these crustaceans are associated with a detrital suspension several centimeters thick on the lagoon bottom (Griffiths and Dillinger, Ecology of Invertebrates, this volume). Preliminary data from Schell (1979) indicate that the detritus on lagoon bottoms may be derived from several sources (coastal erosion and river runoff) and that it directly provides only a small portion of the energy (carbon) necessary to support the benthic community. The majority of the primary production supporting coastal lagoon ecosystems is currently believed to be of marine origin (see Griffiths and Dillinger, this volume, and Campbell, this volume, for a further discussion of this issue).

The relationship between oldsquaws and the benthic community in portions of Lake Michigan is remarkably similar to that in Simpson Lagoon. In Lake Michigan, Peterson and Ellarson (1977) conducted extensive investigations of the feeding ecology of the oldsquaw and found its primary prey to be a single species of epibenthic amphipod (*Pontoporeia affinis*, 82% of winter diet). Field experiments in Lake Michigan by Marzolf (1962, in Peterson and Ellarson 1977) indicated that a thin detrital film (<5 mm) was generally present on the bottom of the lake, and his laboratory experiments suggested that *Pontoporeia* densities were positively correlated with the density of bacteria in this organic matter. Further study in Simpson Lagoon may show a similar relationship between epibenthic invertebrates and detritus-associated bacteria. Griffiths and Dillinger (this volume) have shown that in Simpson Lagoon at least part of the diet of the very common amphipod *Onisimus glacialis* is comprised of *Mysis*. The nature of other possible trophic relationships within the barrier island-lagoon benthic community as a whole (e.g., among the epibenthos, the detritus layer and the inbenthos) is currently unknown.

The standing stock of benthic infauna* (bivalves, polychaetes, cumaceans, tunicates and other organisms) in Simpson Lagoon substrates has been determined to be at least as high (approximately 2.2 g ash-free dry wt/m^2) as that of the mobile epibenthos* (0.1-2.5 g ash-free dry wt/m^2). In spite of high standing stocks of these infaunal organisms, only about 10% of the diet of oldsquaws in Simpson Lagoon was comprised of bivalves (primarily *Cyrtodaria kurriana* and, to a lesser extent, *Portlandia arctica*), cumaceans and polychaetes. Some of these organisms may have been available in the epibenthos, so the percentage of the diet taken from the inbenthos itself may have been even lower than 10%. In Lake Michigan, infaunal organisms (Tubificidae) were also very abundant. At some locations in the lake, maximum densities of 335,000 infaunal organisms/m^2 were reported (Rofritz 1972:56); however, they did not appear in the diet of oldsquaws collected there. These organisms may have burrowed into the sand and silt substrates and were largely unavailable to the ducks.

Another interesting parallel exists between the Simpson Lagoon system and that in Lake Michigan. In both, the diets of the major avian predator, the oldsquaw duck, and the major fish predator, whitefish, were remarkably similar. As discussed earlier, the degree of similarity was high between the diets of ciscos (especially the least cisco) and the oldsquaw in Simpson Lagoon ($\bar{x}$=0.81 ± 0.09, Morisita Similarity Index for all whitefish vs oldsquaw comparisons, see Craig and Haldorson, this volume). Similarly, the diets of the commercially important whitefish (*Coregonus autumnalis*) and of the oldsquaw in Lake Michigan were both comprised principally of *Pontoporeia*, and both fish and ducks concentrated to feed in the same areas where amphipods reached maximum density (Peterson and Ellarson 1977:88).

As mentioned earlier, our results indicated that oldsquaws preyed on large mysids and amphipods and preyed most effectively in areas where the density of prey was high (Figs. 25 and 26). Griffiths and Dillinger (Ecology of Invertebrates, this volume) showed that the density of invertebrates in Simpson Lagoon was not homogeneous. They found that densities of both mysids and amphipods were significantly greater at their deep (2.5 m) lagoon sampling stations, in the central trough near the middle of Simpson Lagoon, than elsewhere. The table below shows that (1) the average depths

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*From Craig and Haldorson, this volume, and Griffiths and Dillinger, this volume.

	1977	1978	
	All Oldsquaws (n=77)	Feeding Oldsquaws (n=81)	All Oldsquaws (n=108)
Depth* (m)	2.09 ± 0.178	2.07 ± 0.179	2.05 ± 0.172

*mean ± standard error

where oldsquaws were collected in Simpson Lagoon during 1977 and 1978 were all slightly greater than 2 m, and (2) these depths were similar during the different years, but (3) these depths were all significantly shallower than those at the mid-lagoon invertebrate sampling stations ($\bar{x}$=2.5 ± 0.0).

Griffiths and Dillinger (this volume) sampled their three mid-lagoon stations at systematic intervals. These stations were established independent of the presence or absence of oldsquaws. We have considered these stations to be 'control' locations and have used them in statistical comparisons with the oldsquaw (and associated habitat) collection locations. Table 57 gives the results of various prey density comparisons (Mann-Whitney 'U' tests) at the control and bird collection locations. In all instances the density of mysids was greater at the two deep water control locations than at bird collection locations averaging a half meter shallower. During the last seven weeks of the 1978 sampling period, the density of amphipods was also greater at the deep control locations.

There were no significant differences in the densities of invertebrates at locations where feeding birds were collected and at locations where birds were indiscriminantly shot. (Continued at top of p. 218.)

Table 57. Results of Mann-Whitney 'U' comparisons of invertebrate densities at locations where oldsquaws were collected (feeding birds, other birds and all birds) and at deep control locations*.

	5 July-5 August 1978			6 July-23 September 1978		
Habitat Comparison	'U'	n_1 and n_2	p	'U'	n_1 and n_2	p
Deep Control vs feeding birds						
Total	9	3, 11	ns	22	4, 14	ns
Mysids	3	3, 11	<0.05	4	4, 14	<0.05
Amphipods	8	3, 11	ns	0	4, 14	<0.002
Deep Control vs other birds						
Total	7	3, 10	ns	3	3, 4	ns
Mysids	2	3, 10	<0.05	0	3, 4	<0.028
Amphipods	7	3, 10	ns	0	3, 4	<0.028
Deep Control vs all birds						
Total	16	3, 21	ns	25	4, 17	ns
Mysids	5	3, 21	<0.05	4	4, 17	<0.02
Amphipods	15	3, 21	ns	0	4, 17	<0.002

*These control locations were Griffiths and Dillinger (Ecology of Invertebrates this volume) Simpson Lagoon sampling stations 3 and 4 which were both 2.5 m deep.

(Continued from bottom of p. 216.)

	5 July- 5 August 1978			6 August- 23 September 1978		
	'U'	n_1 and n_2	p	'U'	n_1 and n_2	p
Total Epibenthos	52	10, 11	ns	18	3, 14	ns
Mysids	41	10, 11	ns	20	3, 14	ns
Amphipods	48	10, 11	ns	6	3, 14	ns

Thus, oldsquaws (1) select large prey items while feeding, and (2) feed more effectively in areas where prey densities are high. However, they feed in shallow waters even though prey densities are significantly greater in the deeper central lagoon waters. The relationship between the relatively deep central trough running the length of the lagoon (within which lie invertebrate Sampling Stations 78-3 and 4) and the invertebrates present there is discussed in more detail by Griffiths and Dillinger (this volume).

We have not investigated rates of predation by oldsquaw. This aspect of the functional feeding response is an important one, since it no doubt would be affected by changes in the density of invertebrates. If dramatic reductions in invertebrate density occur, oldsquaws, fish and other organisms dependent on invertebrates for food may be forced to either (1) move to a more suitable area or (2) increase their searching time (become less efficient). In either case, oldsquaws and fish might be deleteriously affected by reduced energy (fat) reserves, inefficient molt, or retarded growth.

At present, we know little of the movements of flocks of molting oldsquaws. Turnover rates of individuals within flocks or of flocks within a lagoon system are poorly understood. Also, as mentioned earlier, little is known of the predation rates of oldsquaws under natural conditions. Nilsson (1970) indicated that oldsquaws wintering along the coast of south Sweden during 1964-1967 spent 79% of the time they were under observation during daylight hours diving for food; he also reported that the rate of feeding by oldsquaws increased as the ambient temperatures along the coast decreased. Thus, oldsquaws are capable of functional changes in their feeding behavior in response to some types of natural perturbations.

Phalarope Feeding Ecology

Earlier (Johnson 1978) we presented the hypothesis that some combination of oceanographic and meteorologic variables may have combined to make marine invertebrate prey of shorebirds and especially phalaropes more abundant along barrier island shorelines (especially the seaward shorelines) than along mainland shorelines. As mentioned in the results, very few phalaropes were collected along the seaward or mainland shorelines; therefore few data are available to test this hypothesis. Analyses of those few data that are available, however, show no significant differences between invertebrate densities along the seaward and lagoonward shorelines of the barrier islands (Mann-Whitney 'U' tests; two sets of comparisons; early and late August 1978; n_1 and n_2=3, 4 and 2, 4, respectively; $P>0.3$ and >0.05, respectively).

During 1977, no prey organisms other than copepods, which were the principal prey of phalaropes in Simpson Lagoon that summer, were systematically identified to the species level. During 1978, on the other hand, all prey organisms consumed by phalaropes were identified to the species level (see Appendix IX). During 1977 phalaropes preyed heavily on copepods (65% by weight of the total season diet) and amphipods (20% by weight of the total season diet), whereas during 1978 they preyed little on copepods (2% by weight) and mysids (5% by weight) but heavily on amphipods (93% by weight, Appendix IX).

Connors and Risebrough (1976) found that copepods were a major prey item of phalaropes near Barrow, Alaska, during late July through early September 1975 (copepods found in 76% of stomachs examined) and during the late July through late August period of 1976 through 1978 (copepods found in 34% of stomachs examined). Similarly, during early June 1978 near Cape Krusenstern, Alaska (Seward Peninsula), copepods were found in 88% of phalarope stomachs examined by Connors and Risebrough (1978). During fall migration phalaropes also prey heavily on copepods. In the Bay of Fundy, phalaropes concentrate in tide rips and turbulent convergent fronts where copepods are apparently available near the surface of the water (R.G.B. Brown, Canadian Wildlife Service, pers. comm. 1978; Brown et al. 1979).

Copepods, and especially arctic marine copepods, store large quantities of energy in the form of wax (Benson and Lee 1975; Lee and Nevenzel 1979). In fact, copepods are the main producers of waxes in the marine food chain and on a world-wide basis at least half of all the organic substance synthesized by phytoplankton is converted for a time into wax (Benson and Lee 1975). Waxes are a form of lipid that is very high in energy and consequently copepods are rich sources of energy (see Griffiths and Dillinger, Ecology of Invertebrates, this volume) for birds such as phalaropes that prey heavily on copepods.

During two years of intensive studies in Simpson Lagoon, we found that phalaropes consumed quite different prey during August; they consumed primarily copepods in 1977 and primarily amphipods in 1978. Also, the number of phalaropes present in Simpson Lagoon during August 1978 was approximately an order of magnitude less than during August 1977; the numbers of amphipods in the nearshore waters where phalaropes fed during 1978 similarly were an order of magnitude less during 1978 than in 1977. Connors and Risebrough (1977) also found that phalaropes near Point Barrow, Alaska, preyed on different organisms during different years. Phalaropes there preyed mainly on marine copepods in 1975, on marine amphipods in 1976, and on brackish water copepods in 1978. Some authorities (Divoky 1978c; D. Schamel, Univ. of Alaska, pers. comm. 1979) have speculated that these variations in prey consumed by phalaropes in nearshore waters may be related to the presence or absence in the nearshore environment of sea ice and its associated planktonic community.

During a series of observations of the feeding behavior of phalaropes conducted on 5 August 1977, it was noticed that birds of both species were feeding on the small cnidarian (jellyfish) *Euphysa flammea**. Although jellyfish and other soft-bodied invertebrates such as pteropods collectively comprised 12.1% of the estimated volume of food available to phalaropes during 1977 (neither taxon was present in the diet or feeding habitat of phalaropes in 1978), these soft-bodied invertebrates comprised a very small proportion of the stomach contents of phalaropes during 1977 (see Appendix IX). Indeed, during 1977 we found no trace of *Euphysa flammea* in the phalarope stomachs. Because of this difference between behavioral observations and results of stomach analyses, caution should be exercised when interpreting the results of feeding ecology studies of phalaropes (and other species) when visual observations do not accompany stomach analyses. The results of micro-bomb calorimetry determinations have revealed that *Euphysa flammea* represents a relatively significant amount of food energy (5.4 kcal/g ash-free dry wt) for an avian predator such as a phalarope (Griffiths and Dillinger, Ecology of Invertebrates, this volume, discuss the results of oxygen micro-bomb calorimetry trials).

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*Incorrectly identified as *Sarsia princeps* in Johnson (1978).

The daily existence energy requirements of a single phalarope, based on equations given by Kendeigh et al. (1975, 1978) and King (1974), was calculated to be approximately 33 kcal/bird-day. Assuming a coefficient of utilization of approximately 60% (Norton 1970), the total daily gross energy requirement of a single phalarope is 55 kcal/bird-day (approximately 1.0 g ash-free dry wt/day). The estimated total number of phalaropes present in the study area, based on extrapolations of linear densities (birds/km of shoreline) along the 15 shoreline transects surveyed during August 1977 (when phalaropes were at their highest densities during the two year study period, see 'Results', Table 36), ranged from approximately 160 birds on 1 August to a peak of approximately 6100 on 16 August, and decreased to approximately 1120 on 24 August (Table 36). Thus, 6.1×10^3 g ash-free dry wt was the maximum daily requirement in the form of copepods, small amphipods, small mysids and small jellyfish to maintain the total number of phalaropes present in the study area during the period of peak density on 16 August 1977. Quantitative estimates of the standing stocks (g/m^2) of invertebrates at stations along the north and south shorelines of Simpson Lagoon during 1978 are given by Griffiths and Craig (1978). If all phalaropes are assumed to feed 0-20 m from shore, the energy available in mysids and amphipods present in lagoon feeding habitat during 1978 is one to two orders of magnitude more than daily requirements at the time of peak phalarope abundance (mid August).

The energy requirements (~ 3.0 to 9.0×10^4g/August)and the consequent trophic role of phalaropes in Simpson Lagoon during August 1977 and 1978 were insignificant compared to those of oldsquaws (~ 4.5×10^7 to 1.2×10^8 g ash-free wt/season) during their periods of abundance in the lagoon (as discussed in a later part of this report).

However, it is clear that large numbers of phalaropes concentrate along shorelines in the Beaufort Sea to feed and accumulate fat reserves (Johnson 1979a) prior to southward migration. The results of color-marking studies of phalaropes near Point Barrow, Alaska (Connors and Risebrough 1977), suggest that there is rapid turnover in the population of juvenile phalaropes present along shorelines during late August. Thus, total numbers using an area may considerably exceed the maximum number seen at any one time. This information indicates that the Beaufort Sea may be an important area to significant fractions of the total Alaskan populations of both red and northern phalaropes.

As mentioned earlier, during 1977 phalaropes preyed on invertebrates (mainly copepods) in approximately the same proportions as the organisms occurred along the shorelines where the birds fed. During 1978, however, phalaropes preyed selectively on small amphipods and copepods; both of these groups were approximately five times less abundant than mysids, which represented a very small proportion of the phalarope diet (Table 54).

Prey selection of the type exhibited by phalaropes has been documented for other species of shorebirds. Prater (1972) found that although knots (*Calidris canutus*) preyed on species of invertebrates roughly in proportion to their abundance, they selected certain sized bivalves that represented a relatively small proportion of those present in the benthos. In contrast, Bengtson and Svensson (1968) found that two species of abundant shorebirds (*Calidris alpina* and *C. minuta*) did not prey on those species of invertebrates that were most abundant, but that each selected different prey from very distinct habitats. Prater (1972), Bengtson and Svensson (1968) and ourselves all found that shorebirds did not appreciably reduce the standing stocks of the invertebrate fauna upon which they preyed.

Gull and Tern Feeding Ecology

No arctic terns were collected in the Simpson Lagoon study area during 1977, 1978 or 1979. The only period when large numbers of arctic terns were detected in the study area was during their fall migration in

1977, which lasted from approximately 15 to 30 August. During this period both adult and juvenile terns, with smaller numbers of Sabine's gulls, fed at locations between the barrier islands, where mixing of marine and lagoon waters produced turbulence. Both arctic terns and Sabine's gulls were observed picking invertebrates from the surface of the water in these areas; juvenile birds of both species were observed begging for food from adults. Several plankton tows conducted in these areas while birds were feeding indicated that mysids and amphipods were the two most abundant taxa present there.

The diets of glaucous gulls in Simpson Lagoon consisted of a variety of shoreline invertebrates and vertebrates ranging in size from copepods to amphipods, tunicates, bivalves, isopods, small fish and small birds. In relation to the other key bird species examined (phalaropes and oldsquaws), glaucous gulls appear to have adopted an opportunistic feeding strategy along shorelines in the Simpson Lagoon area. Glaucous gulls feeding along coasts in Iceland also consumed a variety of food organisms ranging from small intertidal invertebrates to birds and fish (Ingolfsson 1967).

Belopol'skii (1957) also found that glaucous gulls in the Barents Sea area were opportunistic feeders that ate a wide variety of organisms such as fish, molluscs, small mammals, crustaceans, birds, echinoderms, garbage and berries, with fish, crustaceans, birds and waste comprising the major portion of the diet. Løvenskiold (1964) similarly found glaucous gulls to be highly adaptable and opportunistic feeders in Svalbard during the breeding season. At that time they ate large numbers of eggs and nestlings of other nesting birds, waste of hunter-killed seals and reindeer, and garbage. Hartley and Fisher (1936) noted that in Svalbard glaucous gulls are both scavengers and predators; they killed and ate large numbers of both adult and young birds there. Nathorst (1898 in Løvenskiold 1964) suggested that in locations where birds of prey are scarce, glaucous gulls have adopted predatory feeding habits.

The distribution of gulls in the Simpson Lagoon study area during 1977 (the only year when this species was studied intensively) appeared to be related to the distribution of their food organisms; the mainland shoreline was apparently preferred habitat shortly after breakup, possibly because of the presence of fish in this area; the lagoonward shorelines of the barrier islands were apparently preferred habitats during August, presumably because of the presence of isopods and mysids; the seaward shorelines of the barrier islands were apparently preferred habitats during September 1977 because of the presence of large numbers of large hyperiid amphipods washed up on the beaches at that time.

The existence energy requirements of a glaucous gull, calculated using formulae in King (1974) and Kendeigh et al. (1977), is approximately 390 kcal/bird-day. Assuming a coefficient of utilization of 70%, the gross daily energy requirement is approximately 560 kcal/bird. The energy requirements for the total number of glaucous gulls present along the barrier islands and in Simpson Lagoon, based on the total number of glaucous gulls recorded both on- and off-transect during aerial surveys conducted in these habitats (Table 25), increased from a low in 1977 of approximately 0.2×10^3 g ash-free dry wt/day on 5 June to 32.1×10^3 g ash-free dry wt/day during the period of peak abundance in the three year study, on 22 September 1977. As with the phalaropes, these requirements were insignificant when compared with the overwhelming requirements of oldsquaws during their period of peak abundance in Simpson Lagoon.

The Trophic Role of Birds in an Arctic Marine Lagoon System

Griffiths and Dillinger (Ecology of Invertebrates, this volume, Fig. 27 and Tables 19, 20, 21 and 22) have estimated the amount of food available to and consumed by the major groups of consumers (predators) in Simpson Lagoon during 1977 and 1978; the data for 1978 are the most comprehensive for both the prey available (epibenthic invertebrates) and for the major predators (birds, fish, and *Onisimus glacialis*). Through integration procedures (Johnson and Kiokemeister 1964:240-242), we used the above mentioned data to determine the total season standing stock of prey (food) and the total season energy requirements of the major groups of consumers during the 1977 and 1978 summer period (5 July to 23 September; see Table 58).

The energy requirements of oldsquaws during 1977 and 1978 have been calculated using the recent equation of Kendeigh et al. (1977:201): at 0°C, $M=4.142W^{0.5444}$, where M=daily existence energy requirements (kcal) during the molting period, and W=the weight of the bird (g). Wooley and

Table 58. Total season food requirements of major consumers in relation to standing stock of prey (5 July to 23 September 1978).*

Standing Stock of Available Prey (g$^+$/m^2)		Requirements of Major Primary Consumers							
		Oldsquaw		Fish		*Onisimus*		Total	
		g/m^2	%	g/m^2	%	g/m^2	%	g/m^2	%
1977	48.800**	0.769**	1.602	0.098	0.204	-	-	0.973	2.027
1978	19.210^{++}	0.281	1.457	0.126	0.664	0.056^{++}	0.290	0.463	2.400

*Determined from integration of total season data presented in Griffiths and Dillinger (this volume, Figure 27 and Tables 19, 20 and 22).

$^+$Grams ash-free dry weight.

**Data adjusted upward (from 37.820 and 0.760, respectively) in order to make comparisons over the 80-day period 5 July to 23 September 1977, rather than the 62-day and 79-day periods 15 July to 15 September and 5 July to 22 September, respectively, given in Griffiths and Dillinger (this volume).

$^{++}$Data adjusted upward (from 18.490 and 0.054, respectively) in order to make comparisons over the 80-day period 5 July to 23 September 1978, rather than the 77-day period 8 July to 23 September 1978, given in Griffiths and Dillinger (this volume).

Owen (1978) and Owen (1970) give a digestion efficiency of about 70% for a duck; this value was used to convert existence energy requirements to gross energy requirements. Craig and Haldorson (this volume) give the corresponding values for fish energy requirements. Phalaropes and glaucous gulls played relatively minor energetic roles as consumers in the barrier island-lagoon system, and have not been included in these analyses.

Of the nearly 50 and 20 g/m^2 of invertebrate prey available to consumers in Simpson Lagoon during the 80-day sampling periods in 1977 and 1978, respectively, only 0.97 and 0.52 g/m^2 were required to support the major predators or consumers present there throughout those periods*. Of the total 0.97 and 0.52 g/m^2 required by the major consumers, oldsquaws accounted for well over half of the total energy demands. Thus, the oldsquaw appears to play one of the most important roles as a consumer in Simpson Lagoon. Although several other species of birds are periodically relatively common along the Alaskan Beaufort coast (Johnson 1978, 1979a), oldsquaws are by far the most numerous and are consistently the most densely concentrated species of bird throughout barrier island-lagoon ecosystems during the entire summer ice-free period.

The trophic role of birds in ecosystems has been described during only a few other studies. Wolff et al. (1976:687) summarize the results of most such studies conducted prior to 1975; none of those studies were conducted in marine areas of the Arctic. Table 59 summarizes the trophic role of birds in various ecosystems throughout the western hemisphere.

In their study in the Grevelingen Estuary (Netherlands), Wolff et al. (1976) found that birds required prey equivalent to about 3.5 g ash-free dry wt/m^2-yr, compared to our values of 0.77 and 0.28 g ash-free dry wt/m^2 consumed by oldsquaws during the 80-day summer period in Simpson Lagoon in 1977 and 1978, respectively. About 97% of the prey consumed by birds in the Grevelingen Estuary consisted of benthic invertebrates; this was also the case for oldsquaws in our study of Simpson Lagoon. The major avian predators in the Grevelingen Estuary were shorebirds (mainly the

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*All 'g/m^2' values in this section are ash-free dry weights.

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Table 59. A summary of the trophic role of birds in various ecosystems.

Source	Ecosystem	Location	Period	Food Consumed g ash-free dry wt/m^2	% of Total Food Available*
Wiens (1973)	Temperate Grassland	Central USA	April-August	0.2-0.5	-
Holmes and Sturges (1975)	Temperate Deciduous Forest	New Hampshire, USA	One Year	1.5	0.17
Wiens and Nussbaum (1975)	Temperate Coniferous Forest	Oregon, USA	April-October	2.0-4.2	-
Karr (1971) in Wiens and Nussbaum (1975)	Temperate Bare Ground	Illinois, USA	April-October	0.22	-
Karr (1971) in Wiens and Nussbaum (1975)	Temperate Bottomland Forest	Illinois, USA	April-October	3.20	-
Karr (1971) in Wiens and Nussbaum (1975)	Tropical Ungrazed Grassland	Panama	April-October	0.28	-
Karr (1971) in Wiens and Nussbaum (1975)	Tropical Moist Forest	Panama	April-October	3.3	-
Swennen (1975)	Temperate Marine	Wadden Sea, Netherlands	One Year	3.7	0.53
Wiens and Scott (1975)**	Temperate Marine	Pacific Coast, Oregon, USA	One Year	1.5	-
Wolff et al. (1976)	Temperate Estuary	Grevelingen Estuary, Netherlands	One Year	3.5	0.39
This Study	Arctic Marine Lagoon	Beaufort Sea, Alaska, USA	July-September 1977 July-September 1978	0.77 0.28	1.60 1.45

*This category does not include benthic infaunal organisms that may be unavailable in sublittoral waters.

**Calculated using $\bar{x}$=5.10 ± 0.39 kcal/g dry wt (n=12, Wiens and Scott 1975; Table 3), and total annual energy demand for the 4-species seabird community (Wiens and Scott 1975; Table 2).

oystercatcher), gulls and ducks. Although the main types of birds in our study were similar, shorebirds played a much more prominent role within the Grevelingen Estuary than they did in Simpson Lagoon, primarily because of the periodic tidal fluctuations and consequent exposure of large areas of mud flats in the estuary. No such fluctuations regularly occurred in Simpson Lagoon; consequently diving sea ducks, primarily oldsquaws, played the dominant role as avian predators.

In the Dutch Wadden Sea, Swennen (1975) calculated that carnivorous birds comprised 96% of the total avian biomass and that they consumed 3.7 g ash-free dry wt/m^2 over one year (see Table 59). This amount represented approximately 0.5% of the estimated total standing stock of available food* in that portion of the Wadden Sea. In Simpson Lagoon during the summers of 1977 and 1978, a single species of bird, the oldsquaw duck, consumed the available food at a relative rate about three times (1.5% vs 0.5%) that for all birds in one year in the Wadden Sea.

It should be remembered that most arctic marine estuaries along the north coast of Alaska are shallow (generally 2-3 m deep) and are largely frozen during at least nine months of the year (mid October to mid July). The lagoons therefore do not provide year-round feeding habitat for avian consumers; almost all birds have migrated south and are absent from the Arctic coast during most of the year. Although low densities of prey organisms (largely amphipods) overwinter near the bottoms of these frozen lagoons during winter months (Griffiths and Dillinger, Ecology of Invertebrates, this volume), these organisms do not become abundant until the ice in the lagoons begins to break up in mid to late June.

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*Unavailable food was not included in this calculation.

ECOSYSTEM SIGNIFICANCE AND IMPACT PREDICTIONS

Throughout the course of this study, we have placed strong emphasis on the interrelationships between the various biological and physical disciplines and on investigations of the most important species (key species) and the most important biological and physical processes in the barrier island-lagoon systems. The oldsquaw duck was the most abundant (in numbers and biomass) and was therefore the most important avian consumer within such systems along the north coast of Alaska. Several species of fish (whitefish, char, arctic cod, fourhorned sculpin) and one predatory amphipod (*Onisimus glacialis*) were the only other significant consumers within this ecosystem; marine mammals were scarce in the lagoon systems. During three years of observations, only 16 sightings of seals (mainly *Phoca hispida*) were recorded in the lagoons. Migrating white whales (*Delphinapterus leucas*) were recorded on two occasions (Johnson 1979b) along the seaward coasts of the barrier islands, and no whales were recorded within the barrier island-lagoon systems during the three years of investigations there. One polar bear (*Ursus maritimus*) was present on Pingok Island during September 1977 and tracks of another were seen along the barrier islands during mid September 1979. One large dark whale (either a bowhead or a grey whale) was observed swimming eastward along the southern edge of the pack ice approximately 5 km north of Pingok Island on 2 August 1977.

Other than the oldsquaws, phalaropes (reds and northerns) and glaucous gulls were the only species of birds that were present in large numbers in the lagoons and along the barrier islands. Some attention has been given these last two groups because of their aesthetic importance. But the oldsquaw duck and collectively the various species of commercially and domestically important fish were the most abundant and energetically demanding vertebrates and therefore had the greatest impacts as consumers on the lagoons (and the barrier islands that define the outer limits of the lagoons).

Throughout this study, the standing stocks of invertebrates have always remained at least one or two orders of magnitude greater than the daily energetic demands of migrating fish, of postbreeding (molting) oldsquaws and of postbreeding gulls and phalaropes (Griffiths and Dillinger, Ecology of Invertebrates, this volume). Craig and Haldorson (Ecology of Fish, this volume) have argued convincingly that food has not limited the number of fish or birds that may use the barrier island-lagoon systems. Other factors acting outside the lagoon systems such as those that influence reproductive capacity, or that cause winter mortality, or cause mortality during migration, may play a major role in actually limiting the population sizes of key species that use the barrier island-lagoon systems during the summer season. For oldsquaws, there is direct evidence that production of young in tundra wetlands is directly influenced by such factors as the timing of snowmelt and the productivity of tundra lakes where postbreeding females and young feed throughout most of the summer (Pehrsson 1973, 1974). Similarly, the population sizes of some species of arctic anadromous fish are no doubt limited to a great extent by the amount of overwintering habitat available in inland rivers, streams and lakes (Craig and McCart 1976). Likewise, populations of many of the important species of invertebrates, such as the mysids, may be limited more by events that occur in offshore marine habitats where they reproduce and overwinter, than in the nearshore systems to which the yearlings migrate each spring and spend the summer (Griffiths and Dillinger, Ecology of Invertebrates, this volume).

One may ask, then, why have we placed emphasis on investigations of these organisms and the processes that influence them in the barrier island-lagoon systems of north coastal Alaska during the short summer season? The answer of course is that these organisms are strongly associated with this interface between the harsh but rich marine system of the Beaufort Sea and the warmer (in summer) terrestrial system of the north coastal plain. In this interface, food is super-available. Ample protection from wind, ice and cold water is provided by the barrier island chains (without which the lagoons would not exist) and the waters are relatively warm. These features reduce the maintenance energy requirements of consumers, and thereby allow a large proportion of the energy consumed by aquatic organisms in the lagoon systems to be used for growth (fish and invertebrates), for replenishing depleted energy reserves (fish and birds) and for replacement of insulation and the building of fat reserves prior to migration (birds and in some cases, fish). Significant proportions of the Beaufort Sea populations of oldsquaw, brant and possibly other species pass through the lagoons annually.

In a document recently produced by the U.S. Congress (Library of Congress 1976:151), the coastal zone, of which the barrier island-lagoon system along north coastal Alaska is a part, has been defined as a "band of dry land and adjacent ocean space in which land ecology and use directly interacts with ocean ecology and use. The coastal zone is one of the most sensitive and biologically productive areas of the marine environment. Because of the importance of the coastal zone to marine ecosystems, the environmental impacts from Outer Continental Shelf oil and gas operations are most likely to be most critical in this area". That same document (Library of Congress 1976:114) referred to an oil spill when it stated that "Some of the more notable damage has been done to diving sea birds, to the point where the survival of some species in certain localities has been threatened". King and Sanger (1979) recently assigned reasonably high Oil Vulnerability Index (OVI) values (range 0 to 100) to the oldsquaw (66) and the phalaropes (60) and a lower value to the glaucous gull (45). Indeed, in areas where the history of the effects of oil pollution have been well documented (Joenson 1972a, b and Joenson and Hanson 1977), sea ducks and especially eiders, scoters and the oldsquaw have suffered the greatest mortality (even greater than the auks). Severe oil pollution along the coast of the Beaufort Sea during the summer open water period could affect as many as several hundred thousand oldsquaws, depending on the duration and location of the pollution. For example, during early spring (March) 1979, a small fuel oil spill (no further details available) killed an estimated 10,000 to 20,000 seabirds that had concentrated in a rich feeding area off the coast of northern Norway (Barrett 1979). Even a small and localized spill could have severe effects on oldsquaws when they are highly concentrated in a lagoon, or on snow geese at Howe Island, Alaska's only snow goose colony.

Various authors have dealt in detail with the subject of impact assessment and predictions associated with oil and gas development in coastal marine waters (Bourne 1968; Blumer 1969, 1970; Mironov 1970; Ottway 1970; Hoult 1971; Straughan 1971; Brown 1973; Brown et al. 1973; Vaughan 1973; Boesch et al. 1974; Anderson 1975; Anonymous 1975; National Academy of

Sciences 1975; Bourne 1976; Gorski et al. 1976; Koski and Richardson 1976; Library of Congress 1976; Szozepski 1976; Mackay 1977; Milne 1977; Ross 1977; Norlands Petroleums 1978) but two recent documents (Weller et al. 1978:251-348 and OCS Arctic Project Office 1979) best describe the predicted impacts and suggested mitigative measures and stipulations associated with OCS oil and gas development in the coastal Beaufort Sea.

A variety of unregulated activities associated with oil and gas development could have deleterious effects on various important avian species or species groups along the Alaskan Beaufort Sea area. Activities such as toxic materials spills; icebreaking; low level aircraft overflights; ship, boat, hovercraft or barge movements; ground transportation; excavating and dredging; seismic exploration; drilling; causeway construction between or to coastal islands; river diversion; heated water discharge; road construction on islands; pipeline construction on islands; building construction on islands; erection and presence of communication towers and/or wires; biophysical scientific field research and increased human presence and hunting all could have significant effects on birds. The effects of these activities on birds may be momentary, short-term or long-term; they may be direct or indirect and they may be of an insignificant, moderate or severe nature. Those species or species groups most likely to be affected by such development activities are snow geese, oldsquaws, eiders, gulls and terns, shorebirds, brant, swans, various other species of geese and ducks, and a variety of terrestrial birds. Table 60 presents a general description of the sensitivity and vulnerability of birds in various coastal habitats along the Alaskan Beaufort Sea.

Attempts to predict the results of interactions of these groups of birds with the above mentioned development-related activities are usually qualitative in nature and are often confounded by such variables as the time, place, weather conditions and other unknown variables that inevitably surround such events, and consequently such attempts are often unsuccessful.

Scientifically credible, quantitative studies of disturbance, employing proper controls, are difficult to conduct. The very presence of an observer recording responses of organisms to various types of disturbance is a major source of error. Similarly, misleading anthropomorphic

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Table 60. Sensitivity/vulnerability[†] index for various avian species and habitats in barrier island-lagoon areas along the eastern Beaufort Sea coast of Alaska. (Based on 1977, 1978 and 1979 data and the literature.)

	Habitats							
	Barrier Islands			Lagoon		Mainland Shoreline		Offshore Marine
Species	Gravel	Oceanside Shorelines	Lagoonside Shorelines	Shallow Lagoon	Deep Lagoon	Entire Shoreline	Sagavanirktok River Delta	
Snow Goose[††]						fall staging** (15 Aug-30 Sept)	nesting*** (1 June-30 July)	
Oldsquaw			loafing** (25 July-30 Aug)	loaf-feed* (25 July-30 Aug)	Feeding*** (open water season)			migration** (1 May-5 June)
Brant	nesting** (1 June-30 July)					migration** (20 Aug-5 Sept)		
Eiders	nesting*** (1 June-30 July)			loaf-feed* (1-30 Aug)				migration (1 May-5 June*** and 15 July-10 Sept*)
Phalarope		during high density staging*** (10-30 Aug)	during high density staging** (10-30 Aug)			during high density staging* (10-30 Aug)		
Glaucous Gull	nesting* (1 June-30 July)	during staging* (15-30 Sept)	feeding/staging* (30 Aug-30 Sept)	feeding* (25 July-30 Aug)				
Arctic Tern	nesting*** (1 June-30 July)		feeding/staging* (15-30 Aug)	feeding* (15-30 Aug)				
Loons								feeding** (open water season)

*Sensitive/vulnerable.

**Very sensitive/very vulnerable.

***Critically sensitive/critically vulnerable.

[†] We have applied the term 'sensitive' to barrier island-lagoon habitats that may be easily affected by development-related activities (primarily oil and gas development activities) and we have applied the term 'vulnerable' to species of birds (in some cases whole populations) that may be especially susceptible to development-related activities.

[††] We have included snow geese in this matrix because of their vulnerable position at the nesting colony at Howe Island in the Sagavanirktok River delta and because of their number in the Arctic National Wildlife Range in late summer.

interpretations of responses by animals to disturbance are difficult to avoid. Experience and some experiments have shown, however, that many species of birds accommodate relatively well to certain types of development-related activities (Schweinsburg 1974b; Gollop, Goldsberry and Davis 1974a, b; Gollop, Black et al. 1974). Notable exceptions along the Beaufort Sea coast include snow geese approached by aircraft (at nearly any altitude) during the nesting period (1 June to 30 July) and during the period of fall pre-migratory staging, which occurs from approximately 15 August to approximately 30 September (Salter and Davis 1974; Schweinsburg 1974b; Koski 1977); and aircraft overflights in the vicinity of certain species of seaducks, such as common eiders (Barry and Spencer 1976; Schamel 1974; Korschgen 1977; Schamel, pers. comm., 1978). In particular, Schamel (1974) showed that as aircraft approached, common eiders nesting on Beaufort Sea barrier islands flushed from their nests and thereby exposed their eggs to predation. Schamel indicated (pers. comm., 1979) that the level of disturbance to eiders was most pronounced during the egg-laying and the early incubation period (1 to 30 June).

Leffingwell (1919) mentioned that Duck Island, located in the Sagavanirktok River delta, once supported a large eider colony but that it was exterminated as a result of egg robbing. According to Gavin (1976:60), Duck Island has continued to support very few eiders (2-4 nests/year over a 5-year period) from 1970 through 1974, but that the number of glaucous gulls nesting there over the same period has been substantial (40-54 nests/year over the same 6-year period). These results are especially interesting because they suggest that eiders, once they abandon traditional nesting areas, may not readily return.

Little is known of the effects on molting oldsquaws of disturbance such as chronic aircraft and boat traffic, dredging activities, seismic operations and other developed related activities and associated noise in barrier island-lagoon systems. Seismic operations in Simpson Lagoon during the summer of 1977 appeared to have little lasting effect on nearby flocks of post molting oldsquaws (S.R. Johnson, unpublished data, 1977). However, such information has so far been purely qualitative and has not been based on quantitative experimentation. It has been documented, however, that shortages of protein in the diets of wild birds prior to or during the molt period can cause molt to be slowed or to be interrupted, and Ashmole (1962) reported that an unseasonal shortage of food may cause delays in the onset of molt in wild seabirds.

Our experiences in Simpson Lagoon suggest that molting and post molting oldsquaws were little affected by such activities as systematic collecting with shotguns, by systematic disturbance from small boats moving across and through Simpson Lagoon, by systematic low-level aerial surveys from both helicopters and small fixed-wing aircraft, and by overflights of many other aircraft (Johnson 1978, Appendix Table 14). Oldsquaws did not leave the study area after such disturbances; nor did they cease to frequent certain areas of concentration along the leeward sides of the barrier islands. Experiments by Ward and Sharp (1974) similarly found that molting oldsquaws were only slightly affected by aircraft overflights near Herschel Island, Yukon Territory, during August 1973, and that the documented effects did not appear to be long lasting. Similar results concerning oldsquaws were reported by Sharp (1978) who conducted a study of various bird deterrent measures at McKinley Bay, east of Tuktoyaktuk, N.W.T., during 1977.

Feeding flocks of staging phalaropes showed little overt reaction to our collecting activities (shooting some individuals with shotguns). Many flocks of phalaropes continued to feed while several birds from the flock were collected. However, glaucous gulls became very wary of small boats after a number of encounters with biologists shooting at them from small boats.

CONCLUSIONS

Brief conclusions of the ornithological studies are:

1. Lagoon and nearshore marine habitats were largely frozen when spring bird migration occurred, and birds made minimal use of the area. Any open water created during this time by man's activities might attract large numbers of waterbirds and thereby increase their vulnerability to oil or other contaminants that might accumulate at such sites.
2. Male oldsquaws used shoreleads and cracks in lagoon ice during their molt migration in early July, thereby concentrating in habitats potentially vulnerable to contamination by oil. Male eiders largely by-passed Simpson Lagoon during their westward molt migration.
3. Common eiders, arctic terns and glaucous gulls nested almost exclusively on gravel surfaces of islands, whereas species and densities of nesting birds on tundra portions of islands were unremarkable; it is concluded, therefore, that gravel-surfaced barrier islands are very important to these species and should receive protection during the course of development.
4. Simpson Lagoon and various other lagoons, primarily to the east, were extremely important areas for post breeding (molting and staging) oldsquaws from mid to late July through September; an estimated maximum of 106,000 oldsquaws were present in Simpson Lagoon during late September 1977. Development in coastal lagoons and along barrier islands should proceed only with extreme caution immediately prior to and during the open-water season.
5. Shorelines were important habitats to feeding shorebirds in August; seaward shores of islands were most important, lagoonward shores of islands were of intermediate importance, and mainland shores were of least importance. Shorelines were also important to glaucous gulls throughout the open-water season. Development activities that affect beach habitats during the open-water season should therefore proceed with caution.
6. Glaucous gulls were opportunistic in their diets and feeding strategies; phalaropes and oldsquaws were more specialized.

Phalaropes fed mainly on copepods during 1977 and mainly on amphipods during 1978. Oldsquaws fed mainly on epibenthic mysids and amphipods during both 1977 and 1978. In terms of energy consumed, oldsquaws were the major vertebrate predator in the lagoon. Standing stocks of epibenthic invertebrates were one to two orders of magnitude greater than the daily requirements of the key bird species.

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APPENDICES

Appendix I. Transect survey dates and aircraft types used during aerial surveys conducted in the study area during the period 5 June to 22 September, 1977.

Transect Number	Survey Date and Aircraft Type*						
	5 June	20 June	5 July	28/29 July	15 August	30 August	22 Sept.
1	Bell 205	Bell 205	Bell 206	Bell 206	Not Surveyed	Bell 205	Bell 206
2[+]	Bell 205	Bell 205	Bell 206	Cessna 206	Cessna 206	Bell 205	Bell 206
3[+]	Bell 205	Bell 205	Bell 206	Bell 206	Not Surveyed	Bell 205	Bell 206
4[+]	Bell 205	Bell 205	Bell 206	Cessna 206	Cessna 206	Bell 205	Bell 206
5**	Bell 205	Bell 205	Bell 206	Cessna 206	Cessna 206	Bell 205	Bell 206

*One observer was seated in a front seat and one in a rear seat, on opposite sides of the aircraft. In fixed-wing (Cessna) aircraft, the front observer was seated on the right side; in rotary-winged (Bell) aircraft, the front observer was seated on the left.

[+] Survey altitude was 30 m and survey ground speed was approximately 160 km/h (approximately 100 mph).

**Survey altitude was 15 m and survey ground speed was approximately 90 km/h (approximately 55 mph).

Appendix II. Transect survey dates and aircraft types used during aerial surveys* conducted in the study area during the period 23 June to 23 September 1978.

Transect Number	Survey Date and Aircraft Type[†]									
	23 June	5 July	15 July	25 July	5-6 Aug.	15 Aug.	25 Aug.	5-6 Sept.	15 Sept.	23 Sept.
1	Cessna 206	Cessna 206	Bell 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206
2	Cessna 206	Cessna 206	Bell 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206
3	Cessna 206	Cessna 206	Bell 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206
4	Cessna 206	Cessna 206	Bell 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206
5	Cessna 206	Cessna 206	Bell 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206
6	Cessna 206	Cessna 206	Bell 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206
7	Cessna 206	Cessna 206	Bell 206	Cessna 206	Cessna 206	Cessna 206	-	Cessna 206	Cessna 206	Cessna 206
8	-	Cessna 206	-	Cessna 206	Cessna 206	-	-	Cessna 206	-	-
9	-	Cessna 206	-	Cessna 206	Cessna 206	-	-	Cessna 206	-	-
10	-	Cessna 206	-	Cessna 206	Cessna 206	-	-	Cessna 206	-	-
11	-	Cessna 206	-	Cessna 206	Cessna 206	-	-	Cessna 206	-	-
12	Cessna 206	Cessna 206	Bell 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206
13-1	-	Cessna 206	-	Cessna 206	Cessna 206	-	Cessna 206	Cessna 206	-	Cessna 206
13-2	-	Cessna 206	-	Cessna 206	Cessna 206	-	Cessna 206	Cessna 206	-	Cessna 206
14	-	Beaver**	-	-	Cessna 206	-	Cessna 206	Cessna 206	-	Cessna 206
15	-	Beaver**	-	-	Cessna 206	-	-	Cessna 206	-	-
16	-	-	-	-	Cessna 206	-	-	Cessna 206	-	-
17	-	-	-	-	Cessna 206	-	-	Cessna 206	-	-
18	-	Cessna 206	-	Cessna 206	Cessna 206	-	Cessna 206	Cessna 206	-	Cessna 206
19	-	Cessna 206	-	Cessna 206	Cessna 206	-	Cessna 206	Cessna 206	-	Cessna 206
20	Cessna 206	Cessna 206	Bell 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206
21	Cessna 206	Cessna 206	Bell 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206	Cessna 206

*Survey altitude on all transects except Transect 5 was 30 m and survey ground speed was approximately 160 km/h (100 mph). On Transect 5, the survey altitude was 15 m and survey ground speed was approximately 130 km/h (80 mph).

[†] One observer was seated in a front seat and one in a rear seat, on opposite sides of the aircraft. In fixed-wing (Cessna) aircraft, the front observer was seated on the right side; in rotary-winged (Bell) aircraft, the front observer was seated on the left.

**Survey conducted by USFWS (Arctic National Wildlife Range).

BEST DOCUMENT AVAILABLE

Appendix III. Transect survey dates and aircraft types used during aerial surveys* conducted in the study area during the period 22 June to 23 September 1979.

Transect Number	Survey Date and Aircraft Type†			
	22 June	28-29 July**	31 Aug.-1 Sept.	23 September
1	Cessna 206	Cessna 206	Cessna 206	Cessna 206
2	Cessna 206	Cessna 206	Cessna 206	Cessna 206
3	Cessna 206	Cessna 206	Cessna 206	Cessna 206
4	Cessna 206	Cessna 206	Cessna 206	Cessna 206
5	Cessna 206	Cessna 206	Cessna 206	Cessna 206
6	Cessna 206	Cessna 206	Cessna 206	Cessna 206
7	Cessna 206	Cessna 206	Cessna 206	Cessna 206
8	Cessna 206	Cessna 206	Cessna 206	Cessna 206
9	Cessna 206	Cessna 206	Cessna 206	Cessna 206
10	Cessna 206	Cessna 206	Cessna 206	Cessna 206
11	Cessna 206	Cessna 206	Cessna 206	Cessna 206
12	Cessna 206	Cessna 206	Cessna 206	Cessna 206
13-1	Cessna 206	Cessna 206	-	-
13-2	Cessna 206	Cessna 206	-	-
14	-	Cessna 206	-	-
15	-	Cessna 206	-	-
16	-	-	-	-
17	-	-	-	-
18	-	Cessna 206	-	-
19	Cessna 206	Cessna 206	-	-
20	Cessna 206	Cessna 206	-	Cessna 206
21	Cessna 206	Cessna 206	-	Cessna 206

*Survey altitude on all transects except Transect 5 was 30 m and survey speed was approximately 160 km/h (100 mph). On Transect 5, the survey altitude was 15 m and survey ground speed was approximately 130 km/h (80 mph).

†One observer was seated in a front seat (right side) and one in a rear seat, on opposite sides of the aircraft.

**Two additional transects (Transects 22 and 23) were established along the north coast of the Yukon Territory, Canada, and were surveyed on 30 July 1979. Transect 22 included the coastline, lagoons, spits and bays between the Yukon-Alaska border and the east end of Herschel Island. Transect 23 included the coastline, lagoons, spits and bays between the east end of Herschel Island and the border between the Yukon and Northwest territories. Data from the surveys of these two transects have not been included in this report.

Appendix IV. Methods of estimating the total number of oldsquaws present in Simpson Lagoon, Beaufort Sea, Alaska, during 1977 and 1978.

Because of a difference in the aerial survey procedures between 1977 and 1978 (see Methods section), the methods of estimating the total number of oldsquaws present in Simpson Lagoon during these years were also different.

During aerial surveys conducted in 1977, lagoon Transects 2 and 4 were designed to sample largely lagoon habitats, but small amounts of barrier island and mainland habitats were also sampled on these transects. Oldsquaws observed in these terrestrial habitats were not included in oldsquaw density calculations. The mean densities of oldsquaws in lagoon habitats were extrapolated to the appropriate limits of similar habitats off-transect to arrive at an estimate of the total number of oldsquaws present in Simpson Lagoon.

During 1978, surveys of Transects 2 and 4 were redesigned to sample only lagoon habitats. This design enabled the numbers and densities of oldsquaws in lagoon habitats on each side of the aircraft (0-200 m and 200-400 m from shore) to be counted and calculated separately (this was not possible during 1977). Only the density of oldsquaws on the lagoon side of the aircraft was extrapolated to adjacent lagoon habitats. This provided an estimate that, when added to the total number of oldsquaws counted on the opposite side of the aircraft (the side immediately adjacent to the shoreline), provided the best approximation of the total number of oldsquaws present in a given section of the lagoon.

Transect 3, located at mid-lagoon, was surveyed using identical procedures during both 1977 and 1978. Calculations and extrapolations of densities on this transect are straightforward.

The final estimate of the total number of oldsquaws present in Simpson Lagoon was calculated by simply totalling the estimated numbers present in habitats represented by Transects 2, 3 and 4 (see Table 14).

Appendix V. Total numbers and densities of oldsquaws on all transects and during all aerial surveys in the Simpson Lagoon area during 1977.

TRANSECT NUMBER		5 JUNE	20 JUNE	5 JULY	28/29 JULY	15 AUG.	30 AUG.	22 SEPT.
1	DENS	0.0	0.0	2.2	0.1	-	3.3	3.4
	# ON	0	0	31	1	-	47	49
	#OFF	0	0	3	130	-	739	3
2	DENS	0.0	1.5	26.7	401.8	811.5	73.1	21.6
	# ON	0	23	398	5982	12082	1088	322
	#OFF	0	0	0	8550	2772	400	68
3	DENS	0.0	0.0	2.8	501.3	-	184.6	928.3
	# ON	0	0	35	6165	-	2271	11417
	#OFF	0	0	42	1800	-	2657	9351
4	DENS	0.2	0.8	21.6	516.5	162.0	68.0	220.1
	# ON	3	11	280	6687	2097	881	2849
	#OFF	0	0	0	1245	550	2131	5736
5	DENS	2.6	3.2	1.9	1.2	5.8	0.0	0.0
	# ON	35	44	26	16	79	0	0
	#OFF	0	6	0	3	0	0	0
OVERALL	DENS	0.6	1.2	11.4	278.9	346.1	63.4	216.5
TOTAL	# ON	38	78	770	18851	14258	4287	14637
TOTAL	#OFF	0	6	45	11728	3322	5927	15158

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Appendix VI. Total numbers and densities of oldsquaws on all transects and during all aerial surveys along the Alaskan Beaufort Sea coast during 1978.

TRANSECT NUMBER		29 JUNE	9 JULY	15 JULY	25 JULY	5/6 AUG.	15 AUG.	25 AUG.	5/6 SEPT.	15 SEPT.	23 SEPT.
1	DENS	0.0	0.1	2.5	17.6	0.2	0.0	50.1	20.2	193.4	1.5
	# OB	0	2	35	251	3	0	716	287	2750	22
	#OFF	0	0	55	60	0	0	3629	1312	337	25
2	DENS	1.3	160.4	1345.1	289.7	324.8	996.9	337.4	150.2	47.0	9.9
	# OB	19	2388	23326	4239	4836	14813	5826	2236	700	147
	#OFF	0	4510	76	831	325	1037	64	38	150	16
3	DENS	0.0	5.4	39.3	73.0	62.5	7.3	33.3	12.3	29.6	231.8
	# OB	0	66	489	898	769	90	618	151	364	2851
	#OFF	0	132	755	517	55	300	259	53	68	711
4	DENS	0.0	2.7	72.0	19.1	6.4	0.0	0.8	0.1	7.1	138.6
	# OB	0	28	917	267	83	0	10	1	92	1796
	#OFF	2	0	453	0	15	75	201	77	3	1670
5	DENS	1.3	1.4	0.1	0.0	0.0	0.0	2.0	0.1	0.0	0.0
	# OB	15	19	2	0	0	0	27	1	0	0
	#OFF	0	12	1	8	0	0	0	0	0	0
6	DENS	1.8	14.5	1009.1	572.7	215.4	679.7	287.7	296.4	6.9	1.1
	# OB	19	80	7973	3151	1198	3740	1503	1356	38	17
	#OFF	0	160	233	0	1655	403	235	23	22	0
7	DENS	0.0	1.5	6.2	1.9	20.9	106.7	0.0	33.1	11.4	0.0
	# OB	0	13	60	12	125	691	0	195	74	0
	#OFF	0	0	0	8	205	2	0	15	11	15
8	DENS	-	0.5	-	2.2	16.9	-	0.0	4.5	-	-
	# OB	-	12	-	73	383	-	0	103	-	-
	#OFF	-	30	-	9	500	-	0	122	-	-
9	DENS	-	0.6	-	0.0	6.2	-	0.0	4.1	-	-
	# OB	-	7	-	0	75	-	0	50	-	-
	#OFF	-	19	-	0	20	-	0	1	-	-
10	DENS	-	0.0	-	0.0	0.0	-	0.0	0.0	-	-
	# OB	-	0	-	0	0	-	0	0	-	-
	#OFF	-	0	-	15	0	-	0	0	-	-
11	DENS	-	0.0	-	19.3	4.7	-	0.0	33.4	-	-
	# OB	-	0	-	97	22	-	0	150	-	-
	#OFF	-	0	-	110	0	-	0	108	-	-
12	DENS	5.9	5.4	749.0	190.2	212.4	174.2	435.4	115.2	26.4	126.1
	# OB	62	41	13926	2648	2956	2425	6060	1603	367	1755
	#OFF	325	15	586	440	2799	290	520	685	106	325
13-1	DENS	-	1.1	-	0.0	29.6	-	14.2	2.9	-	6.3
	# OB	-	8	-	0	175	-	101	21	-	50
	#OFF	-	0	-	0	451	-	0	80	-	2265
13-2	DENS	-	5.1	-	29.7	128.7	-	178.5	172.5	-	203.4
	# OB	-	252	-	1670	6617	-	8896	6597	-	12131
	#OFF	-	481	-	512	3561	-	2650	579	-	8393
14	DENS	-	0.0	-	-	121.4	-	0.0	87.7	-	0.0
	# OB	-	0	-	-	4203	-	0	3098	-	2
	#OFF	-	0	-	-	1219	-	0	15750	-	0
15	DENS	-	0.0	-	-	179.1	-	0.0	28.8	-	-
	# OB	-	0	-	-	10274	-	0	1652	-	-
	#OFF	-	0	-	-	7393	-	0	112	-	-
16	DENS	-	-	-	-	137.5	-	0.0	26.0	-	-
	# OB	-	-	-	-	6257	-	0	1511	-	-
	#OFF	-	-	-	-	1020	-	0	1975	-	-
17	DENS	-	-	-	-	11.6	-	0.0	95.1	-	-
	# OB	-	-	-	-	420	-	2	1909	-	-
	#OFF	-	-	-	-	691	-	0	287	-	-
18	DENS	-	18.4	-	2.3	53.4	-	0.2	279.0	-	127.5
	# OB	-	621	-	75	1785	-	8	9165	-	4169
	#OFF	-	467	-	28	1565	-	6	24577	-	16042
19	DENS	-	0.0	-	1.6	3.6	-	0.7	22.2	-	0.0
	# OB	-	0	-	11	25	-	5	155	-	0
	#OFF	-	0	-	63	0	-	0	230	-	1950
20	DENS	0.0	0.1	0.0	0.0	1.9	6.1	16.0	64.5	0.3	63.7
	# OB	0	1	0	0	5	21	26	167	3	105
	#OFF	0	10	5	0	10	0	10	7	0	0
21	DENS	0.0	6.1	2.6	22.0	8.3	19.1	23.4	46.3	22.1	26.3
	# OB	0	94	35	342	124	285	309	689	338	340
	#OFF	0	0	1	0	1	616	55	175	118	3873
OVERALL	DENS	1.1	10.3	380.1	45.8	99.6	199.0	116.1	73.8	42.6	114.5
TOTAL	# OB	115	3648	39936	13513	40165	22065	23213	78001	4727	23690
TOTAL	#OFF	327	7040	1611	2552	21465	2093	7629	46049	849	33291

Appendix VII. Total numbers and densities of oldsquaws on all transects and during all aerial surveys along the Alaskan Beaufort Sea coast during 1979.

TRANSECT NUMBER		22 JUNE	28/29 JULY	31 AUG./ 1 SEPT.	23 SEPT.
1	DENS	0.0	4.2	24.6	15.7
	# ON	0	60	350	224
	#OFF	0	70	150	0
2	DENS	2.5	520.5	78.4	231.0
	# ON	37	7703	1167	3428
	#OFF	0	528	300	0
3	DENS	0.0	132.0	329.3	3.4
	# ON	0	1623	4043	42
	#OFF	0	2297	6264	32
4	DENS	0.2	31.1	0.0	113.1
	# ON	3	402	0	1464
	#OFF	0	162	0	330
5	DENS	0.6	8.5	0.0	0.0
	# ON	8	116	0	0
	#OFF	4	0	0	0
6	DENS	0.0	361.1	219.1	1.6
	# ON	0	2310	1331	9
	#OFF	0	90	1	176
7	DENS	0.2	32.0	23.8	30.0
	# ON	1	207	154	194
	#OFF	0	355	0	18
8	DENS	0.2	4.5	9.4	8.4
	# ON	5	102	214	190
	#OFF	0	477	191	504
9	DENS	0.2	28.9	0.0	6.7
	# ON	2	352	0	82
	#OFF	0	0	0	1
10	DENS	0.0	0.0	0.0	197.8
	# ON	0	0	0	2791
	#OFF	41	0	0	91
11	DENS	0.2	58.5	150.7	0.0
	# ON	1	284	746	0
	#OFF	0	50	750	1
12	DENS	24.1	446.0	98.6	128.5
	# ON	337	6240	1379	1797
	#OFF	158	803	0	248
13-1	DENS	10.1	49.2	-	-
	# ON	67	325	-	-
	#OFF	20	0	-	-
13-2	DENS	1.3	217.2	-	-
	# ON	67	10827	-	-
	#OFF	53	590	-	-
14	DENS	-	371.7	-	-
	# ON	-	13110	-	-
	#OFF	-	130	-	-
15	DENS	-	289.0	-	-
	# ON	-	17678	-	-
	#OFF	-	570	-	-
16	DENS	-	-	-	-
	# ON	-	-	-	-
	#OFF	-	-	-	-
17	DENS	-	-	-	-
	# ON	-	-	-	-
	#OFF	-	-	-	-
18	DENS	-	20.6	-	-
	# ON	-	670	-	-
	#OFF	-	2830	-	-
19	DENS	4.8	23.2	-	-
	# ON	31	150	-	-
	#OFF	0	0	-	-
20	DENS	0.0	0.0	-	174.6
	# ON	0	0	-	452
	#OFF	0	0	-	10
21	DENS	1.1	2.8	-	12.5
	# ON	16	42	-	186
	#OFF	0	0	-	443
OVERALL	DENS	2.5	174.2	53.8	66.1
TOTAL	# ON	575	61907	9384	10859
TOTAL	#OFF	279	8952	7656	1854

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Appendix VIII. Numbers of charadriiformes sighted on a frequently surveyed shoreline transect* on Pingok Island, Alaska, during 1977 and 1978.

	SPECIES																							
	Black-bellied Plover		Ruddy Turnstone		Pectoral Sandpiper		Baird's Sandpiper		Dunlin		Semipalmated Sandpiper		Sanderling		Red Phalarope		Northern Phalarope		All Phalaropes		Glaucous Gull		Arctic Tern	
Date	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978
August																								
2	0	0	0	0	0	0	1	0	2	0	29	0	0	0	4	0	-	0	4	0	0	0	0	0
3	0	-	1	-	0	-	5	-	1	-	2	-	0	-	77	-	53	-	130	-	0	-	0	-
4	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	1	-	0	-	0	-	1	-	0
6	0	-	7	-	0	-	1	-	0	-	0	-	0	-	193	-	60	-	253	-	1	-	3	-
7	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0
8	0	-	18	-	0	-	1	-	0	-	1	-	0	-	525	-	51	-	686	-	0	-	1	-
9	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0
10	0	-	5	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	338	-	3	-	0	-
11	-	0	-	0	-	0	-	0	-	3	-	0	-	0	-	30	-	0	-	33	-	0	-	0
12	0	-	1	-	3	-	6	-	1	-	1	-	0	-	69	-	23	-	116	-	0	-	0	-
13	-	0	-	1	-	0	-	0	-	0	-	0	-	0	-	4	-	0	-	4	-	0	-	0
14	0	2	11	0	6	0	3	0	29	2	6	0	0	0	16	7	0	0	16	0	0	-	0	-
17	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	4	-	0	-	4	-	0	-	0
19	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	26	-	8	-	34	-	0	-	0
21	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0
23	0	-	0	-	2	-	0	-	13	-	0	-	0	-	262	-	52	-	364	-	0	-	60	0
24	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0
26	2	0	0	1	2	0	0	0	7	5	0	0	1	0	24	7	17	1	41	8	6	0	15	0
28	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	4	2	0	-	0	0	0	0	9	8	0	0	3	0	0	0	0	0	0	238	1	0	26	0
September																								
2	3	2	0	2	0	0	0	0	9	6	1	0	5	1	0	0	0	0	0	0	0	0	0	0
3	-	2	-	0	-	0	-	0	-	0	-	0	-	0	-	3	-	1	-	4	-	12	-	3
4	0	-	0	-	0	-	0	-	0	-	0	-	1	-	0	-	0	-	0	-	0	-	0	-
6	0	-	2	-	0	-	0	-	37	-	0	-	0	-	0	-	0	-	0	-	2	-	0	-
8	1	-	0	-	0	-	0	-	0	-	0	-	3	-	0	-	0	-	0	-	0	-	0	-
12	6	-	0	-	0	-	0	-	66	-	0	-	17	-	17	-	0	-	17	-	18	-	0	-
16	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-
18	6	-	0	-	0	-	0	-	2	-	0	-	2	-	0	-	0	-	0	-	2	-	0	-

*This transect was located along the lagoonside shoreline of Pingok Island, (see Fig. 1). The dimensions of this transect, 1.2 km x 20 m (0.024 km²), were slightly different from other shoreline transects.

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Appendix IX. Prey organisms consumed by red and northern phalaropes in Simpson Lagoon during August 1977 and 1978.

Taxon	August 1977 (n=46)			August 1978 (n=16)		
	% wt*	% Occurrence	% Hynes Point	% wt	% Occurrence	% Hynes Point
Mollusca	-	-	-	-	-	-
Pteropoda	[4]	[2]	[0.7]	-	-	-
Crustacea	-	-	-	-	6	-
Branchiopoda	tr	2	0.2	-	-	-
Copepoda	45	50	50	1	25	17
Calanoida	8	13	-	-	-	-
Calanidae	1	4	-	-	-	-
Calanus cristatus	1	2	-	-	-	-
Calanus hyperboreus	3	9	-	tr	19	-
Calanus glacialis	tr	9	-	tr	19	-
Pseudocalanidae						
Microcalanus sp.	tr	2	-	-	-	-
Microcalanus pygmaeus	1	4	-	-	-	-
Pseudocalanus sp.	0.5	2	-	-	-	-
Pseudocalanus minutus	0.5	6	-	tr	12	-
Metridiidae						
Metridia sp.	1	6	-	-	-	-
Metridia lucens	1	17	-	-	-	-
Metridia longa	3	15	-	tr	6	0
Centropagidae						
Limnocalanus grimaldi	1	2	-	-	-	-
Chiridius sp	tr	4	-	tr	6	0
Parachaeta norvegicus	1	4	-	-	-	-
Total copepods	[67]	[67]	[50]	[2]	[56]	[17]
Malacostraca						
Mysidacea						
Mysidae	8	13	-	-	-	-
Mysis littoralis	-	-	-	5	12	4
Total mysids	[8]	[13]	[19]	[5]	[12]	[4]
Cumacea	tr	2	-	-	-	-
Amphipoda	20	24	29	65	12	-
Gammaridae	-	-	-	17	25	-
Gammaracanthus loricatus	-	-	-	1	6	-
Gammarus setosus	-	-	-	4	6	-
Onisimus glacialis	-	-	-	6	31	-
Total amphipods	[20]	[24]	[29]	[93]	[62]	[79]
Euphausiacea	[1]	[2]	[0.2]	-	-	-
Insecta	[1]	[6]	[0.9]	-	-	-
TOTAL	101	-	99.8	100	-	100

*% wet weight.

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PART 4. FISH

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TABLE OF CONTENTS

Page

SUMMARY 388

ACKNOWLEDGEMENTS 390

INTRODUCTION 391

  General Nature and Scope of Study 391

  Objectives 393

  Relevance to Development 394

CURRENT STATE OF KNOWLEDGE 395

STUDY AREA 396

  The Annual Cycle 397

  Tides 398

  Temperature and Salinity 398

  Turbidity 399

  Dissolved Oxygen 405

METHODS AND RATIONALE OF DATA COLLECTION 406

  Summer Programs 406

    1977 406
    1978 406
    1979 407

  Winter Programs 407

    All Years 407
    1977-78 407
    1978-79 409

  Summer Methodology 409

    Gill Nets 409
    Fyke Nets 413
    Faber Net 414
    Beach Seine 415
    Pole Seine 415
    Fish Tagging 417
    Other Methods 417

  Winter Methodology 418

  Estimation of Daily Ration 419

    Stomach Evacuation Rate 419
    Feeding Periodicity 421

  Physical and Chemical Measurements 422

TABLE OF CONTENTS (cont'd)

Page

Laboratory Analysis of Fish 422

Parasites 423
Food Habits 423

GENERAL RESULTS 426

Fish Population in Simpson Lagoon 426

Species Composition 426
Relative Abundance 427
Biomass 431

Habitat Utilization 433

Nearshore (Brackish Water) versus Offshore (Marine) Distribution 433
The "Edge Effect" 436
The Shoreline Corridor 443
Summer Distribution 450
Winter Distribution 452

Effects of Physical Factors 456

Fish Movements 460

Seasonal Movements 461
Residency Time in Simpson Lagoon 475

Population Numbers 480

Population Estimates of "Catchable" Arctic and Least Cisco 480
Estimated Densities of Combined Species 486

Feeding Ecology 490

Trophic Spectrum 492
General Food Habits and Food Chain 498
Principal Prey 500
Selectivity 509
Feeding Areas 513
Food Requirements of Fish 516

Influence of Other Organisms 522

Human Use of Fish Resources 522
Predators 528
Parasites 529

Additional Life-History Data for Fishes 532

Arctic Cisco 532
Bering Cisco 551
Least Cisco 553
Arctic Char 564

TABLE OF CONTENTS (cont'd)

Page

Boreal Smelt 569
Fourhorn Sculpin 578
Arctic Cod 586
Saffron Cod 598
Broad Whitefish 601
Humpback Whitefish 605
Arctic Flounder 605
Capelin 607
Salmon 607
Other Species 609

GENERAL DISCUSSION 610

Characteristics of Arctic Fish Populations 610

Fish Use of Nearshore Habitats 615

Implications of Feeding Ecology 615

Food Supplies 615
Factors Contributing to Food Abundance 617

Factors Influencing Fish Activities 622

Feeding and Growth 625
Migration 627
Spawning and Overwintering 629

CONCLUSIONS 632

RECOMMENDED FURTHER RESEARCH 635

LITERATURE CITED 637

APPENDIX 1 - Tag and recapture data for fish recovered during this study, Simpson Lagoon 1977-79 651

APPENDIX 2 - A fish survey in the lower Colville River drainage with an analysis of spawning use by arctic and least cisco 657

SUMMARY

During the brief open-water season along the Beaufort Sea coastline, the relatively warm and brackish waters of Simpson Lagoon and nearshore waters in general provide important habitat for several anadromous species (arctic cisco, least cisco, arctic char) and marine species (arctic cod, fourhorn sculpin). It is postulated that there are physiological advantages, and perhaps requirements, for at least the anadromous species to remain in the nearshore environment.

Nearshore habitats are used by fish for one overriding purpose, namely feeding on the abundant nearshore food supply. Each spring as the ice melts, anadromous and marine fishes invade nearshore waters and feed extensively on epibenthic invertebrates (organisms living on or near bottom substrates). The fish accumulate food reserves for spawning and/or overwintering requirements. Dietary overlap among fishes (and between fish and birds) was high; a few mysids (*Mysis litoralis*, *M. relicta*) and amphipods (*Onisimus glacialis*) accounted for most of the prey eaten. Throughout the open-water period the available invertebrate supply of prey in the lagoon averaged about 1-2 orders of magnitude greater than the total daily food requirements of all vertebrate consumers (fish and birds) in Simpson Lagoon (Griffiths and Dillinger 1980).

Seasonal use of nearshore habitats by fish differed greatly. Anadromous fish arrived with the first signs of spring breakup, dispersed along the coastline, and returned in fall to river drainages to spawn and/or overwinter. Marine species tended to increase in nearshore waters as the open-water season progressed. For all species, numbers of juvenile and adult fish at specific locations in the lagoon constantly changed because of day-to-day pulses of movement and large-scale population movements over periods of several weeks. Fishes appeared tolerant, for at least short periods, of a wide range of water temperatures, salinities, and turbidities; few specific responses to these variables were documented.

In summer, fish were distributed throughout nearshore waters, but anadromous fish were most abundant along the shoreline, and highest concentrations often occurred within 100 m of the mainland shore; marine species tended to be more evenly distributed in nearshore waters.

Species composition and distribution changed in winter. Most anadromous fish left coastal waters, but several marine species (principally arctic cod and fourhorn sculpin) and one anadromous species (boreal smelt) were caught under the ice between Prudhoe Bay and the Colville River. These fish eventually left shallow areas (< 2 m deep) as ice thickened and salinities increased; they used deeper nearshore habitats for spawning and/or overwintering. Two anadromous species, arctic and least cisco, overwintered in the brackish waters (18-32‰ salinity) of the Colville Delta.

Fish tagged in Simpson Lagoon were recaptured in domestic, commercial and sport fisheries at several locations along the Alaskan Beaufort Sea coastline. The commercial fishery in the Colville Delta harvests an estimated 9% of the arctic cisco and 5% of the least cisco that are susceptible to the fishery. Domestic fishing by the village of Nuiqsut, also located in the Colville Delta, may harvest a similar amount. Effects of this fishing pressure on arctic fish stocks are not known.

Several factors influencing the numbers and distribution of nearshore fishes were examined but predation pressure, parasite loads and food supply were not considered to be limiting to these fish populations. However, a continual immigration of prey into Simpson Lagoon from marine waters was necessary to insure an adequate food supply for fish in their preferred nearshore habitats (Griffiths and Dillinger 1980). A disruption of this immigration process, or disruption of the exchange rates in general between nearshore brackish waters and offshore marine waters, would probably reduce the food supply for nearshore fishes.

In summary, Simpson Lagoon is a rigorous estuarine environment which appears to be maintained at an early stage in ecological succession because of widely fluctuating physical factors (e.g., temperature, salinity, substrate gouging and resuspension, and periodic freezing). The lagoon is essentially a shallow (< 3 m deep), frequently wind-churned and turbid channel of water. Successful species in this environment tend to be mobile and/or tolerant of a wide range of conditions. This, in turn, suggests that--at least in summer--the relatively few species tolerating these conditions would not be overly sensitive to related types of small-scale physical perturbations that might result from industrial activities.

ACKNOWLEDGEMENTS

It has been a pleasure interacting with the many people involved in this project. Acknowledgement of the help and interest provided by individuals from BLM, NOAA, OCSEAP, LGL, and associated researchers is presented in the introductory section of the overall program report. We especially acknowledge Joe Truett, Carl Walters and Bill Griffiths for their stimulating discussions and overall improvements to our program. Benny Gallaway, Alan Birdsall and Joe Margraf also provided fresh ideas and administrative support for the project. Howard McElderry played an especially active and interested role in carrying out the field program. Jim Helmericks provided knowledge of arctic fish and reliable logistic support. We also appreciate the help of Rob Dillinger and Tim Byers for analysis of invertebrates, Hugh Bain for fish aging, Brian Harvie and Nell Stallard for data analysis and many of the people listed above for assistance in the field. Our report has also been improved by the editorial comments of John Richardson and Joe Truett.

INTRODUCTION

The nearshore environment along the Beaufort Sea coastline provides essential habitat for several arctic fishes, including the anadromous species utilized by man. During the short arctic summer, large numbers of marine and anadromous fish enter coastal waters and feed extensively on nearshore food resources. Anadromous fish accumulate food reserves to support them through the arctic winter, and adult fish must reach a critical level of food reserves or they will not spawn (Bolotova 1976). During winter months, several species of marine fish continue to use nearshore water for feeding and spawning.

General Nature and Scope of Study

In 1976, LGL Ecological Research Associates (LGL) initiated an interdisciplinary study of a barrier island-lagoon ecosystem on Alaska's Beaufort Sea coast. The purpose of this program was to identify and analyze those components and processes that contribute significantly to the structure and productivity of the nearshore ecosystem. The program began with a review and planning phase, followed by an active research program in 1977-1979. Truett (1980) provides a summary of the general objectives of the program.

Simpson Lagoon (Fig. 1) was selected as the study site because (1) it was reasonably typical of island-lagoon systems along the Beaufort Sea coast, (2) prior human disturbance to the area was relatively limited, (3) it was reasonably accessible, and (4) some baseline data for the area were available.

From the onset of the program, fish populations were identified as a significant component of the island-lagoon ecosystem. Fish were an important part of the short food chain operating in nearshore waters, and fish were important to humans residing along the Beaufort Sea coastline. Therefore, field studies were conducted to examine fish resources in Simpson Lagoon and assess their vulnerability to Outer Continental Shelf development.

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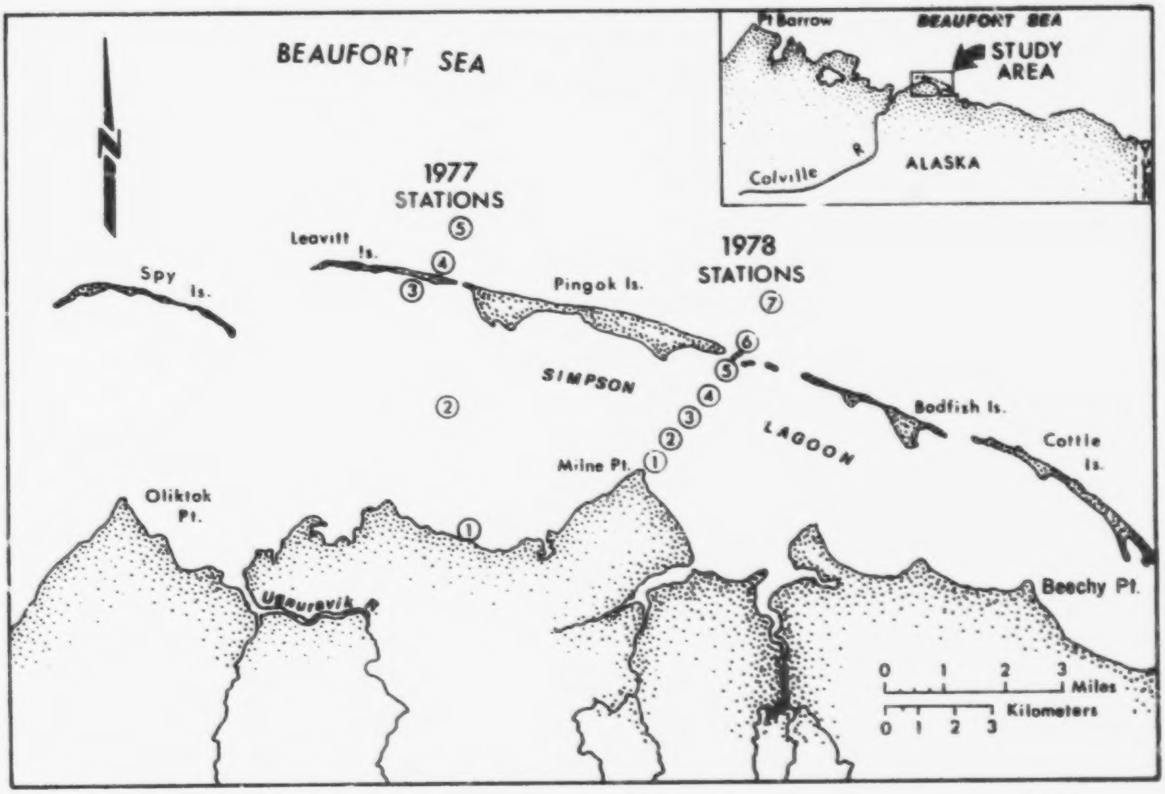
BEAUFORT SEA
N
1977 STATIONS
⑤
④
③
②
①
Leavitt Is.
Spy Is.
Pingok Is.
1978 STATIONS
⑦
⑥
⑤
④
③
②
①
SIMPSON LAGOON
Bodfish Is.
Cottle Is.
Milne Pt.
Oliktok Pt.
Ugnuravik R.
Beechy Pt.
0 1 2 3 Miles
0 1 2 3 Kilometers
Pt Barrow
BEAUFORT SEA
STUDY AREA
Colville R.
ALASKA

Figure 1. Map of Simpson Lagoon study area, showing summer sampling stations in 1977 and 1978.

Research emphasis in this study was directed towards those species identified to be of special interest to society or thought to be biologically important to these species. The fishes identified in this manner were three anadromous species (arctic cisco, least cisco, arctic char) and two marine species (arctic cod, fourhorn sculpin).

The three anadromous species were considered important because they are the principal fish taken in most subsistence, commercial and sports fisheries along the Alaskan Beaufort Sea coast. These species are also widely distributed and abundant in coastal waters; they account for almost 50% of the fish biomass present in the summer. Ciscoes and char are major consumers of the secondary production (invertebrates) in lagoon waters.

The two marine species were included as important species because they are the numerically dominant fish in Beaufort Sea coastal waters, also accounting for about 50% of the fish biomass present. They too are major consumers of secondary production in lagoon waters, and the arctic cod is, in turn, a valuable food item for birds, marine mammals and humans.

Objectives

The present study examined nearshore fishes and their ecological role in a barrier island-lagoon system. As previously described, the principal fishes selected for study were the arctic cisco, least cisco, arctic char, arctic cod and fourhorn sculpin. Specific objectives of the fisheries studies were:

1. Identify the principal uses (spawning, rearing, migrating, overwintering) of the barrier island-lagoon ecosystem by important fish species.
2. Determine fish utilization of habitat types during open-water and winter periods, and assess reasons for differential utilization of various habitats.
3. Document the timing of fish movements, the residency time of fish in specific lagoon waters, and patterns of coastal migration.
4. Assess food sources, feeding dependencies and daily ration of fish in nearshore waters. Examine trophic relationships of fish with predators and prey.

5. Examine human use of fish resources.
6. Document life-history characteristics of fishes in the barrier island-lagoon ecosystem and adjacent waters.

Relevance to Development

Scenarios describing potential environmental impacts of petroleum exploration and production in coastal waters of the Beaufort Sea have been developed (Milne and Smiley 1976; Weller et al. 1978; Bureau of Land Management 1979). Burns (1978) lists the following categories of development activities that are likely to cause environmental impacts:

Planned Activities

1. Establishment of settlements and support sites
2. Establishment of utility or transportation corridors including roads, piers, pipelines, utility lines, airfields, storage areas, etc.
3. On-site development and production structures (platforms, rigs, ice islands, etc.)
4. Marine transport

Unplanned Activities

1. Fuel spills
2. Losses and discharge of drilling muds (also including disposition of drill cores and escape of formation water)
3. Well blow-out (gas)
4. Petroleum facility fires
5. Major spills of crude oil, including well failures.

Many of these activities will affect fish populations directly (e.g., oil spills, water withdrawal from critical overwintering habitats) or indirectly through alterations of fish habitat (e.g., gravel removal, changes in temperatures and salinities resulting from man-caused changes in nearshore currents) or alterating of water quality (e.g., fuel spills, releases of drilling muds and formation waters).

CURRENT STATE OF KNOWLEDGE

Petroleum discoveries in the arctic have prompted a variety of fisheries studies over the past decade. Most studies have been of a catalogue and inventory nature since little fisheries information was available when oil and gas were found at Prudhoe Bay in 1968-69. Since that time, surveys of freshwater areas over much of the North Slope have been conducted with emphasis along the Sagavanirktok River where the Alyeska oil pipeline was built in 1974-76. Regions east of the Colville River received more attention by fisheries biologists than regions west of the river, since industry once proposed building another pipeline from Prudhoe Bay across the Arctic National Wildlife Range and into Canada.

During this same period, inventories of coastal fishes were also initiated, again with emphasis on locations between the Colville and Mackenzie rivers (Roguski and Komarek 1972; Alt and Kogl 1973; Ward and Craig 1974; Kogl and Schell 1974; Galbraith and Hunter 1979; Kendel et al. 1975; Hablett 1980). Coastal sites where more detailed studies have been conducted are: Barrow (Cohen 1954; Wohlschlag 1954 and 1956), Prudhoe Bay (Furniss 1975; Doxey 1977; Bendock 1977), Barter Island (Griffiths et al. 1977), Nunaluk Lagoon (Griffiths et al. 1975), the Yukon coast (Craig and Mann 1974; Kendel et al. 1975) and the Mackenzie Delta (Mann 1974, 1975; Slaney 1974; Percy 1975; deGraaf and Machniak 1977). Topics such as species distribution, relative abundance, general food habits, age-length relationships and basic life-history data have been the emphasis of most studies, and a general picture of fish use of nearshore waters has gradually emerged. However, only recently has attention been paid to the problems of trophic relationships, locations of overwintering areas, stock identification, effects of offshore petroleum development and resource management.

Fish use of offshore waters remains poorly documented. Virtually all fisheries studies to date have described fishes, particularly the anadromous species, inhabiting shallow nearshore waters, which are typically less than 3 m deep. Little is known about the distribution, abundance and ecological role of marine fishes in offshore waters, although an important contribution to this subject is a recent deep-water (40-400 m) survey by Frost et al. (1978).

STUDY AREA

Simpson Lagoon, located between Prudhoe Bay and the Colville River delta on Alaska's North Slope (Fig. 1), is a large and partially enclosed body of water measuring approximately 35 km in length and 3-6 km in width. To the north, Simpson Lagoon is protected from direct ocean exposure by a chain of barrier islands in the Jones Island group. Some of these islands are composed of gravel and sand (Spy and Leavitt islands) while others are partly covered by tundra (Pingok, Peat, Bertoncini, Bodfish and Cottle islands). The mainland forms the southern boundary of the lagoon and is characterized by slumping tundra banks (1.5-3.0 m in height) and narrow beaches composed of silt, sand and gravel.

There are three principal pathways for water exchange into and out of Simpson Lagoon (1) the far western exit between Spy Island and Oliktok Point, (2) the large gap between Spy and Leavitt islands, and (3) the far eastern entrance between Cottle Island and Beechey Point. In addition, there are several small and shallow channels between the various islands. Flushing rates of lagoon waters are estimated to be 10-20% exchange per day under normal conditions and up to 100% exchange per day during exceptionally strong winds (65 km/h) (Mungall 1978).

Although 14 small tundra creeks flow directly into Simpson Lagoon, water exchange in the lagoon during the open-water season is dominated by coastal currents of the Beaufort Sea. For much of that season, the waters flowing through the lagoon originate partly from North Slope rivers lying to the east of the study area. Because of prevailing easterly winds and westward-flowing currents, river waters discharged into the nearshore Beaufort Sea generally flow from east to west and remain in the nearshore zone. Thus, Alaska's largest North Slope river, the Colville, which empties into Harrison Bay immediately west of Simpson Lagoon, has surprisingly little direct hydrological influence on the lagoon despite the closeness of its discharge. During spring breakup in 1977 and 1978, overflow from the Colville onto the ice did not enter the lagoon, and for the remainder of the season prevailing westward-flowing currents tended to carry the Colville's discharge to the west rather than through Simpson Lagoon. A reversal in the prevailing direction of nearshore currents occasionally occurs during the summer when storm winds blow from the west.

Simpson Lagoon is a shallow-water basin with an average depth of only 2 m and a maximum depth of 3 m. Outside Simpson Lagoon on the seaward side of Pingok Island, ocean depths drop to 2 m within 50 m of the shoreline and to 10-15 m within 1 km.

The lagoon floor is uniformly flat and almost featureless. In most areas, a layer of detritus covers substrates of mud and sand. The detrital layer, which varies in thickness up to 2 cm, is not consolidated, but consists of a flocculent, amorphous mass above which mysids and amphipods move about. Numerous small holes in the detritus are further signs of animal activity.

Some topographic relief on the lagoon floor is provided by shallow ice gouge marks in the central portion of the lagoon and occasional tundra clumps and piles of stones throughout. These stones, which measure approximately 2.5 cm in width, serve as a base for attached laminarian algae, 30-45 cm in length.

The Annual Cycle

The ice-free period in Simpson Lagoon is short, lasting about 3 months. Initial stages of spring breakup consist of flooding from the Kuparuk and Ugnuravik rivers in early June, subsequent drainage of much of this water through the ice, and the formation of open-water leads along mainland and island shorelines in mid-June. By late June and early July, shoreleads are 10-100 m wide and contain cold (0-4.5°C), clear and almost fresh waters (2.1-6.0 ppt). Most nearshore ice soon melts or is moved away by winds and currents, and the lagoon is 90% ice-free by mid-July.

Ocean ice may hold fast against the outside of the barrier islands until mid- or late July, at which time the ice is moved about 10 km offshore by winds. Thereafter, ice floes occasionally are blown back to the islands by wind, but the lagoon itself remains ice-free for the duration of the summer.

Freeze-up begins in the lagoon in late September, when slush ice forms in shallow, calm waters. Lagoon waters were open on 1 October 1978, although ice cover probably developed over the entire lagoon during the next two weeks.

During winter months, surface ice steadily increases in thickness. In November, the ice is 20 cm thick and maximum thicknesses of about 2 m are reached in late winter (April). At this time, approximately 90% of the lagoon volume is frozen solid and the only unfrozen water is located in the lagoon center where under-ice depths are 0.3-1.0 m, and in the deeper channels between the islands.

Tides

Tidal fluctuations along the Beaufort Sea coastline are small and irregular (Johnson and Hartmann 1969; Lewellen 1970). Daily fluctuations in water levels are often only 10-15 cm, although wind-generated changes may be greater (e.g., Griffiths et al. 1975 and 1977). The maximum recorded difference between highest and lowest water levels over the open-water season was 90 cm in Nunaluk Lagoon (1974) and 75 cm in Kaktovik Lagoon (1975) (Griffiths et al. 1975 and 1977).

Temperature and Salinity

Seasonal changes in the physical environment present stringent conditions for life in Simpson Lagoon. Summer salinities run the gamut from fresh to saline water, and in winter the water may become hypersaline (up to 68 ppt, Crane 1974). Water temperatures range from summer highs of 10-13°C to winter lows of -2°C. A generalized seasonal pattern for these physical characteristics is as follows:

Spring (late June-early July): waters cold (0-5°C) and nearly fresh (1-10 ppt) because of melting ice and river flooding.

Summer (mid-July-mid-August): waters relatively warm (7-10°C) and brackish (18-25 ppt).

Fall (late August-September): rapid cooling (0-6°C), waters brackish (18-25 ppt).

Winter (mid-October-Early June): water cold (1 to -2°C) and initially brackish (25-30 ppt), becoming saline or hypersaline (35-60 ppt) by winter's end.

Lagoon waters are generally warmer (2-4°C) and less saline (4-5 ppt) than waters outside the barrier islands. Because of the warming effect of the sun on shallow lagoon waters and because coastal circulation patterns tend to hold discharge from North Slope rivers near the coastline, waters become progressively cooler and more saline with increasing distance from the mainland shore (Figs. 2 and 3). An exception to this pattern was observed in 1977 when an apparent upwelling brought cold marine water against the outside of the barrier islands.

Little vertical stratification of temperature or salinity occurs in the lagoon. In 1978 bottom conditions were generally within 1°C and 3 ppt salinity of surface conditions. In the deep channel (3-4 m) between Spy and Leavitt islands, however, a tongue of cold hypersaline water was recorded (C. Mungall, pers. comm.). Similar hypersaline pockets of water were recorded in deep (4 m) pools in Kaktovik Lagoon in summer (Griffiths et al. 1977).

In winter, water temperatures are cold (-2 to +1.5°C) and salinities increase through the winter as ice cover thickens (Table 1). Under-ice water may become hypersaline in shallow enclosed areas where there is limited exchange with offshore waters. Simpson Lagoon became hypersaline by late winter (Fig. 4).

Turbidity

Lagoon waters are turbid to varying degrees for almost the entire open-water period. Because of variations in wind-generated turbulence, nearshore turbidity readings fluctuated widely (1-146 NTU recorded 80 m from shore) from day to day. Wave-washed waters around the lagoon edges are generally more turbid than waters elsewhere; there is often a band of murky water along the shoreline (Fig. 5). Maximum turbidities occurred during and after periods of high winds; the correlation between turbidity (measured almost daily in 1978,80 m from the shoreline) and wind speed was highly significant (correlation coefficient $r = 0.629$, $P < 0.001$, $n = 56$). After winds slacken, turbidity readings fall rapidly as the sediments quickly settle out.

1977

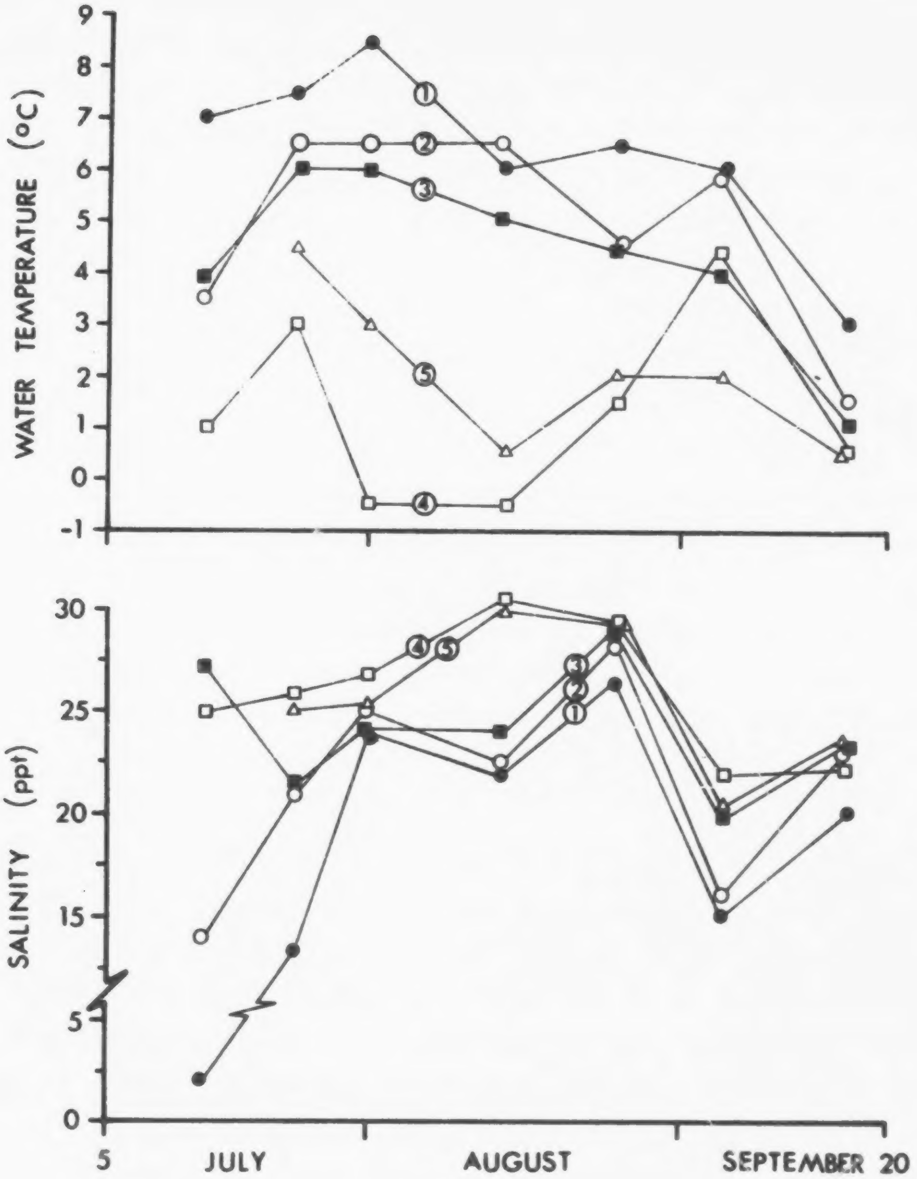

Figure 2. Seasonal variation in temperatures and salinities at Stations 1-5, 1977.

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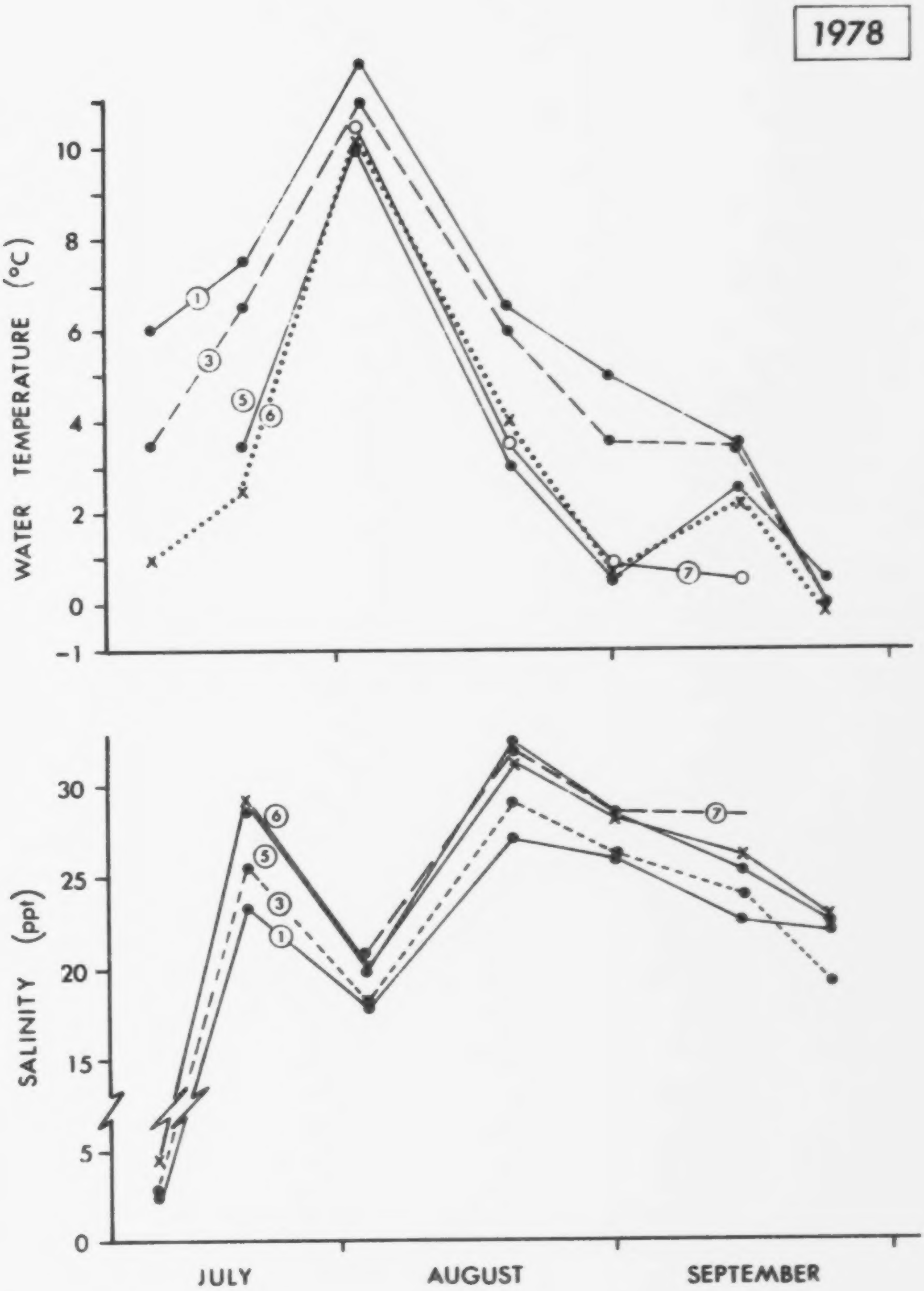

Figure 3. Seasonal variation in temperatures and salinities at Stations 1, 3, 5, 6 and 7, 1978.

Table 1. Physical conditions at sampling stations during early and mid-winter (see Figs. 6 and 7 for locations).

Station	Date	Depth (m) Ice	Depth (m) Water	Water Temp. (°C)	Salinity (ppt)
Colville A	5 Apri. 78	2	1.5-4.5	-1.0 to -1.3	18-25
Colville B	5 Apr. 78	2	10.7	-1.0 to -1.7	19-32
Thetis Island	11 Nov. 78	0.7	3.0	-1.0 to -1.2	24-28
	26 Feb. 79	1.6	2.1	-	28.0
Simpson Lagoon	11 Nov. 78	0.7	2.4	-1.5 to -2.0	24.0
	24 Feb. 79	1.6	1.2	-2.0	36.0
Boulder Patch	11 Nov. 78	0.7	5.8	1.5	23.0
	27 Feb. 79	1.6	4.9	-	28.5
Narwhal Island	11 Nov. 78	0.7	12.1	-	-
	25 Feb. 79	1.6	10.6	-	28.0

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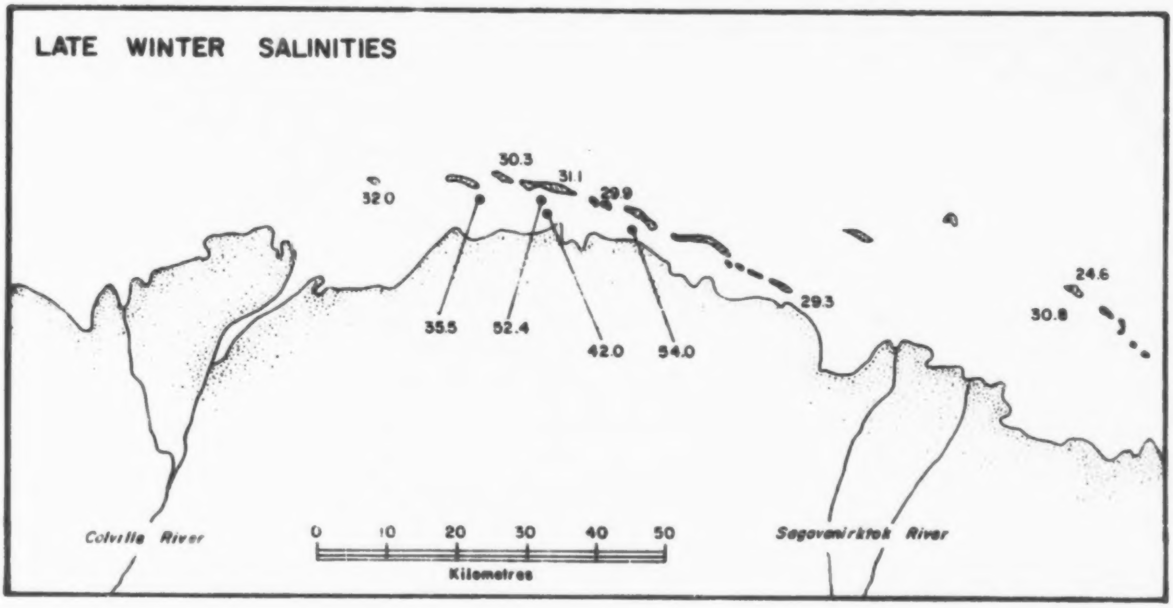
LATE WINTER SALINITIES
32.0
30.3
31.1
29.9
35.5
52.4
42.0
54.0
29.3
24.6
30.8
Colville River
Sagavanirktok River
0
10
20
30
40
50
Kilometres

Figure 4. Late winter salinities (ppt) in nearshore coastal waters, 12-14 May 1979.

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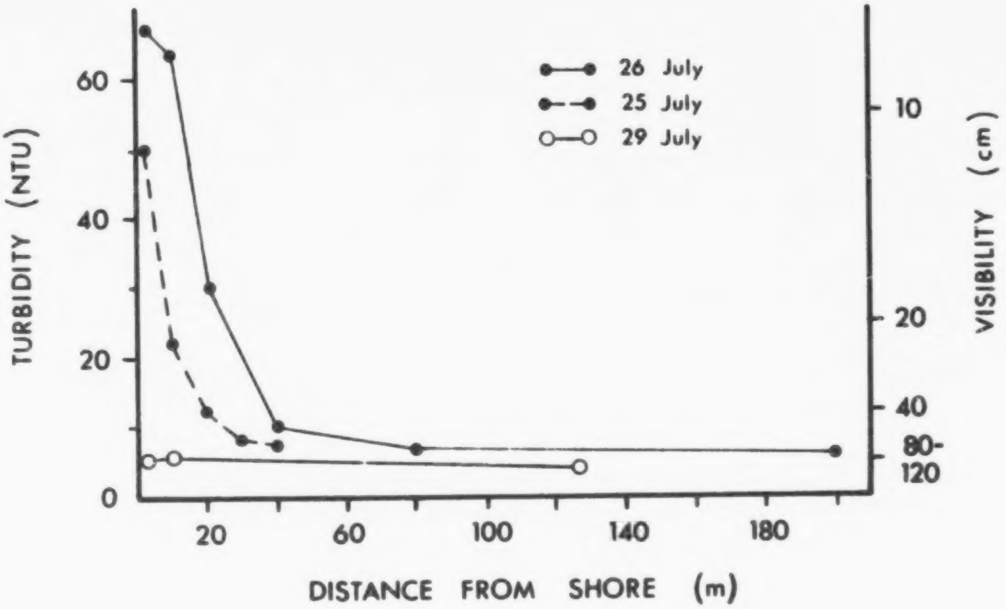

Figure 5. Turbidity profiles on east side of Milne Point, 1978. Water depths were shallow: 0.9 m deep at 20 m offshore; 1.4 m deep at 200 m offshore.

Simpson Lagoon, despite its shallow nature, is not a homogeneous mixture of wind-churned water. SCUBA divers observed that a vertical stratification of water currents occurred in the lagoon center even though the water depth was only 2 m. Currents were slower at the bottom and thus the flocculent detrital layer often remained in place despite relatively high velocities of overlying water.

Dissolved Oxygen

Dissolved oxygen concentrations remained high at all stations during the open-water period. The average summer value in 1977 was 9.8 ml/ℓ (range 7.0-12.0 ml/ℓ, n = 40).

METHODS AND RATIONALE OF DATA COLLECTION

The fisheries program consisted of both summer and winter field studies in Simpson Lagoon and nearby waters. Sampling was most intensive during three periods: the open-water seasons of 1977 and 1978 and the winter of 1978-1979. A chronology of summer and winter sampling programs follows.

Summer Programs

1977

In order to document fish use of Simpson Lagoon and identify important areas for fish, the 1977 field program was designed to sample representative nearshore habitats in time and space during the open-water season. Five habitats (Fig. 1) were sampled on a regular basis:

Station No. (1977)	Habitat Type	Water Depth (m)
1	mainland shoreline	0-1.2
2	lagoon center	2-2.5
3	island shoreline (lagoon)	0-1.2
4	island shoreline (ocean)	0-1.2
5	offshore ocean	8-10

The temporal sampling scheme during 1977 consisted of (1) a spring breakup period (16 June-5 July) when sampling was restricted to open-water leads around Pingok and Leavitt islands, and (2) a summer period when samples were taken at approximately 10-day intervals at all stations. Sampling ended 23 September, when lagoon waters were beginning to freeze. During each sampling period and at each location, the water-column was sampled by a variety of techniques to insure adequate collection of fish present.

1978

In 1978, the field camp was moved from the west end of Pingok Island to Milne Point for ease of logistic support, and the locations of the 1978 sampling program reflect this change (Fig. 1). Most fisheries studies were conducted at Station 1 or at other locations along the mainland shoreline; the remainder of the stations served primarily as collection sites for invertebrates (Griffiths and Dillinger 1980) although ichthyoplankton samples were taken at most sites. As in the previous year, the 1978 summer sampling program (19 June-24 September) spanned the open-water season.

1979

A brief sampling effort was carried out in mid-summer (17-28 July 1979). The fisheries objective was to tag arctic and least cisco in order to estimate population sizes. Fyke nets were operated at Milne Point (17-24 July), Kavearak Point (17-29 July) and Pingok Island (25-27 July). Additional fish were caught by beach seine.

Winter Programs

All Years

As part of our winter studies, we monitored the fall commercial fishery in the Colville River; this fishery is operated by Jim Helmericks each October-December in the lower delta near Anachlik Island (Fig. 6). The Colville is a major source of the ciscoes and whitefishes using Simpson Lagoon in summer--many fish tagged in Simpson Lagoon were recaptured here. Through mark/recapture ratios of tagged and untagged fish, we have estimated the population sizes of arctic and least ciscoes in nearshore habitats.

1977-78

A late-winter sampling program was conducted in the Colville Delta to determine the use of these brackish waters by anadromous and marine fishes. Under-ice gill nets were set at Stations A and B in Kupigruak and East Channels in April and May 1978 (Fig. 6).

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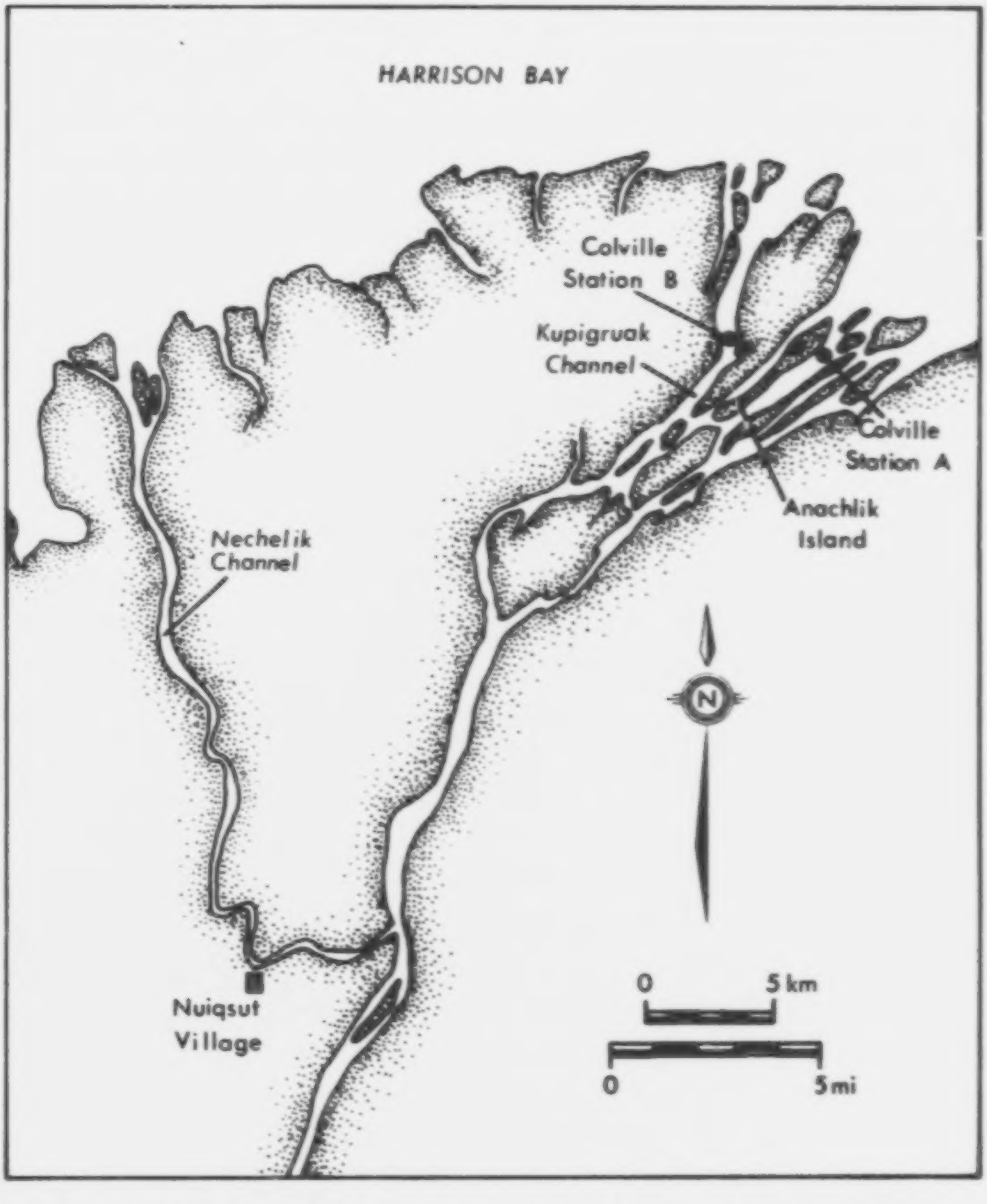
HARRISON BAY
Colville Station B
Kupigruak Channel
Colville Station A
Anachlik Island
Nechelik Channel
Nuiqsut Village
N
0
5 km
0
5 mi

Figure 6. Locations of winter gill net samples (Stations A and B) in the Colville Delta, April-May 1978. Also shown are Nuiqsut Village (residents fish throughout the delta) and Anachlik Island where a commercial fishery (Helmericks) operates. Many tagged fish from Simpson Lagoon were recaptured in this fishery.

1978-79

An extensive sampling program was conducted in nearshore waters during November, February and March-May. Because virtually nothing was known about the winter use of nearshore areas of the Beaufort Sea by fish, we chose to sample a variety of nearshore habitats rather than concentrate efforts only in Simpson Lagoon. Four principal sampling sites were near Thetis Island, in Simpson Lagoon, in the "Boulder Patch" in Stefansson Sound, and near Narwhal Island (Fig. 7). Thetis Island was selected for investigation because it lies off the mouth of a major North Slope river where physical and biological conditions might be very different than in other coastal areas. The Boulder Patch, a deep-water site protected by the barrier islands, was examined because it supports a biologically diverse assemblage of flora and fauna which differs greatly from that occurring in surrounding waters (Dunton and Schonberg 1979). Narwhal Island was selected for comparative purposes because it lies outside the barrier islands. This site was difficult to sample in early winter because of the shifting ice pack.

Summer Methodology

A diagrammatic comparison of principal sampling gear used along shorelines during the 1977 and 1978 open-water seasons is shown in Fig. 8; gear dimensions are listed in Table 2.

Gill Nets

Gill net #5 (Table 2) was used in 1977. In shallow waters at Stations 1-4, this net sampled the entire water-column; both sinking and floating gill nets were used in deeper (10 m) waters at Station 5. Stations were first sampled soon after the ice melted and thereafter at approximately 5-12 day intervals. Gill net sets were usually 24 h in duration but sometimes varied (from 10-120 h) because ice and weather conditions interrupted the normal routine. Total number of sets and days fished between 24 June and 18 September 1977 are listed below.

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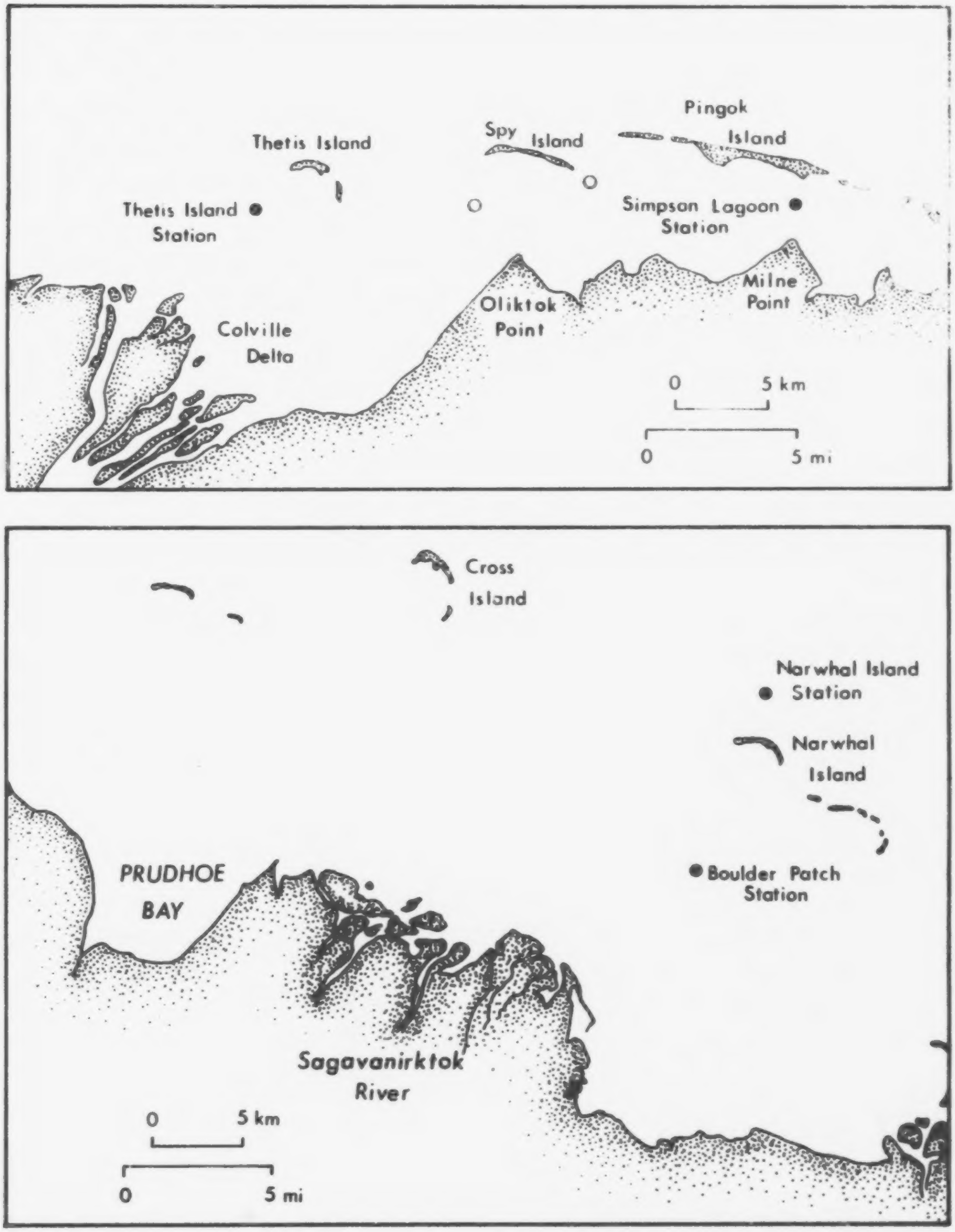
Pingok
Island
Spy Island
Thetis Island
Thetis Island Station
Simpson Lagoon Station
Colville Delta
Oliktok Point
Milne Point
0 5 km
0 5 mi
Cross Island
Narwhal Island Station
Narwhal Island
Boulder Patch Station
PRUDHOE BAY
Sagavanirktok River
0 5 km
0 5 mi

Figure 7. Winter sampling sites between the Colville Delta and Narwhal Island, 1978-79. Primary stations (solid dots) and incidental sites (open circles) are indicated.

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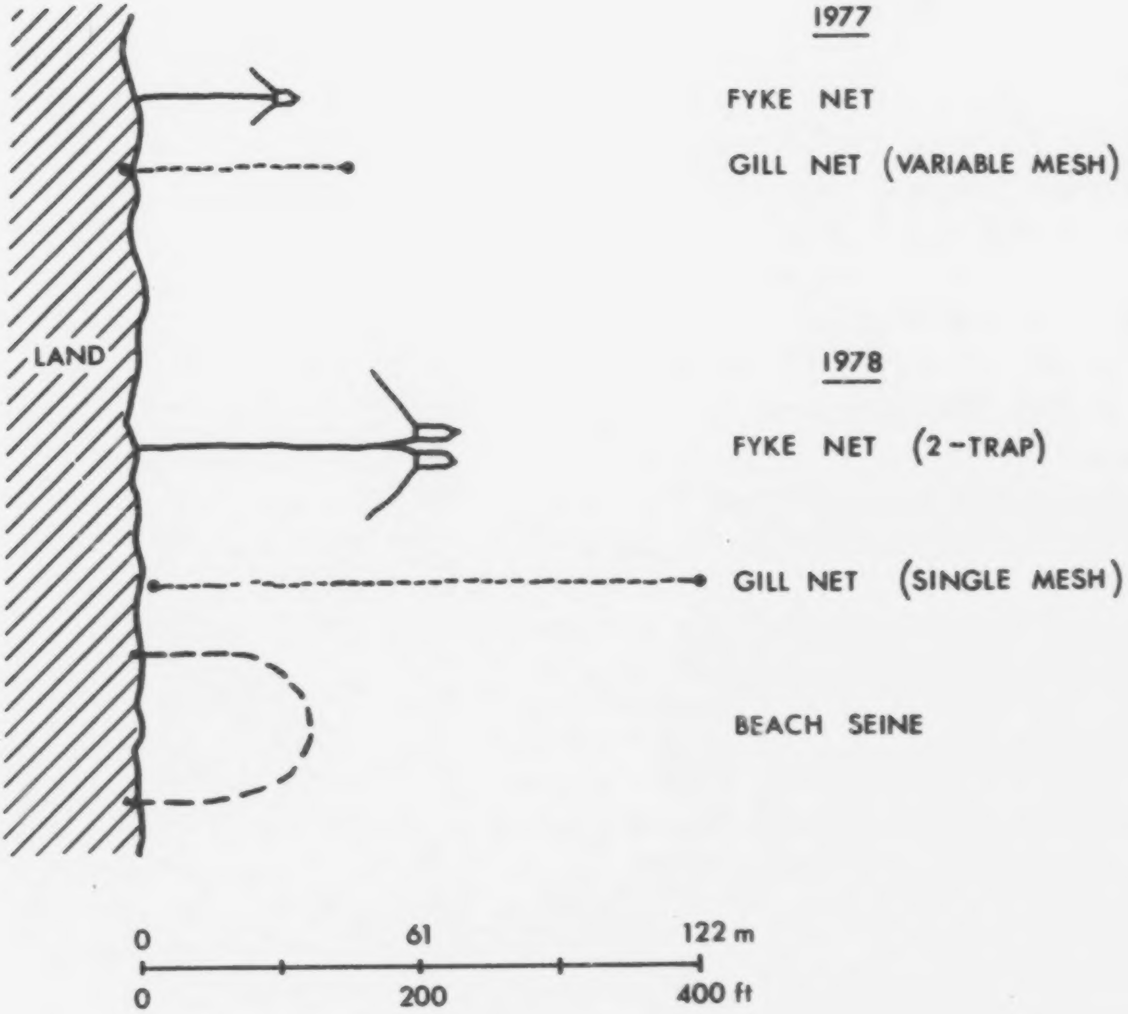
1977
FYKE NET
GILL NET (VARIABLE MESH)
LAND
1978
FYKE NET (2-TRAP)
GILL NET (SINGLE MESH)
BEACH SEINE
0
61
122 m
0
200
400 ft

Figure 8. Fish sampling gear used during open-water studies along shorelines.

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Table 2. Descriptions of sampling gear.

Net Type	Major Dimensions	Mesh Size (Stretched)	Material, Comment
Gill Net #1	400' x 6' (single panel)	2"	Monofilament
Gill Net #2	150' x 6' (2 75' panels)	75' x .75", 75' x 1"	#210/2 multi-filament
Gill Net #3	150' x 6' (3 50' panels)	50' x 1", 50' x 1.5" 50' x 2"	#69 Monofilament
Gill Net #4	150' x 6' (4 37.5' panels)	37.5' x 1", 37.5'x 1.5" 37.5' x 2", 37.5'x2.5"	1", 1.5", 2" #69 Monofilament 2.5" #104 Monofilament
Gill Net #5	150' x 6' (5 30' panels)	30' x 1", 30' x 1.5" 30' x 2", 30' x 2.5" 30' x 3.5"	Monofilament
Trammel Net	150' x 6' (triple panel)	Outer walls - 3" Inner walls - .75"	3 " - #139 Monofilament .75 - #210/2 Multifilament
Fyke Net 1977	Lead net 100' x 4' Wing nets 25' x 4' Trap - 4' x 4' x 15' (2 throats)	1" lead & wing nets .5" trap	#44/5 Green nylon
Fyke Net 1973	Lead net 200' x 4' Wing nets 50' x 4' Mouth - 6' x 4' Trap - 12' x 3' x 3' (2 throats: 6" x 10"	1" lead & wing nets .5" trap	Lead & wings #63 knotless nylon, dark gray Trap - #147 knotless Nylon - dark gray
Fyke Net #1 Under-Ice	Four leads 90' x 6' Trap = 6' x 6' x 6' (4 mouths) (4" diameter throat)	.5"	Ace knotless nylon
Fyke Net #2 Under-Ice	Same as above except 2' deep		
Faber Net	0.5 m diameter Mouth 3 m long	1.024 mm	
Beach Seine	360' x 6'	2.5"	Equipped with mud rollers
Pole Seine	10' x 6'	.25"	Nylon mesh
Minnow/ Amphipod Trap	40 cm diameter 1 m long One mouth each end	1/8"	Knotless nylon
Box Trap Under-Ice	4' x 4' x 4' 4 mouths 1.5' diameter	1/32"	Nylon mesh

Station (1977)	1977 Seasonal Totals Gill Net Sets	Days Fished
1	10	10
2	10	19
3	10	10
4	7	10
5	7	10.5

A longer gill net, #1 (Table 2), was used in 1978 to determine the micro-distribution of fish relative to the shoreline. The 2 in mesh size used on this net is particularly effective in catching char and ciscoes in coastal waters (Griffiths et al. 1975). The net was marked at 2 m intervals so that the locations of captured fish along the net could be recorded. The net was set perpendicular to the shoreline with a 2- to 3 m gap between the net and shore. The rationale for leaving this gap was to insure that fish trying to avoid the net would be able to swim around both ends and thus not bias our estimates of their distribution by being funneled into the net at the shoreward end. Water depths were typically 0.3 m at the landward end of the net and 1.5 m at the seaward end. The gill net was set for short time periods (usually 1-3 h) because of the effectiveness of the net at catching fish and to minimize the possibility that fish would avoid areas where many fish were already caught. In some cases, a transect longer than 122 m was sampled by sequentially resetting the net at increasing distances of 122 m farther offshore for equal time intervals.

Fyke Nets

Fyke nets proved to be useful and efficient in sampling fish, including juveniles too small to be caught by gill nets. The style of net, as well as the location and manner of operating the net, differed between the two summers of operation (Fig. 8, Table 2).

During spring breakup of 1977, fyke nets were operated in open-water leads along Pingok and Leavitt islands, but catches were small. Permanent fyke net stations were established at Stations 1 and 3 on 25-27 July 1977 and operated almost daily until 22 September 1977. The fyke trap was generally situated in 1 m of water so that the top of the trap was 20 cm out of the water. Nets were checked daily, weather permitting. Fish were emptied from the cod end of the trap into a holding pen attached to a boat. Specimens were identified and measured; those large enough were also tagged.

In 1978, the design of the fyke net was improved in several respects: (1) lead and wing nets were doubled in length, (2) the trap was enlarged, (3) the net color was changed to gray, and (4) two traps were used simultaneously so that the direction of fish movement could be determined (Fig. 8). This net appeared to be more efficient than the 1977 version; more fish and a wider size range of fish were caught. On one memorable occasion, a single trap held over 25,000 cod (60-140 mm in length) with no observable fish mortality.

Because of the large number of fish caught during 1978, only subsamples were measured. All fish caught were counted, with the exception that during peak catches of arctic cod, numbers of this species were estimated. Estimates were obtained by counting the number of cod in a dip net filled to a given level, repeating this for several additional samples, and then applying the mean number per net-full to the total number of net-fulls in the trap.

The Milne Point region was sampled by the two-trap fyke net in 1978. Because wave action on the east side of the point interfered with the operation of the net, and because a submerged gravel bar extended westward from Milne Point, the fyke net was located on the west side of the point approximately 500 m from the tip. The net operated almost the full length of the open-water season (30 June-24 September 1978). Fish caught in this fyke net were assumed to be traveling east or west and parallel to shoreline. However, the submerged gravel bar off Milne Point may have deflected some of the westward-swimming fish, causing them to miss the trap and thus biasing our judgements of the proportion of fish swimming in each direction.

Faber Net

A modified Faber net (Faber 1968) was used to catch planktonic fish (Table 2). In 1977, each tow filtered approximately 82 m^3 of surface water (i.e., a 5-min tow at 1.4 m/s). Each value presented is the average of two replicate tows at a sampling site. In 1978, three replicate tows were conducted and the volume of water filtered was measured directly by a current meter installed in the mouth of the net.

Beach Seine

In 1978, a 91.4 m (300 ft) beach seine was used to estimate numbers of fish in the usually turbid shoreline waters. The net was set with the aid of a Boston Whaler powered by a 50 hp motor. While one end of the net was held onshore, the seine was set in a curve, returning to shore approximately 35 m down the beach from the starting point. Water depth on the deep side of the net was generally 1.2 m. The net was then pulled onto shore, and captured fish were counted, measured and released; large fish were also tagged.

The area swept by the seine was estimated in order to calculate fish densities. The enclosed sampling area was bounded by a shoreline length of 35 m (± 3 m) and a 91-m length of net. Using these dimensions, the area seined was 980 m^2 if rectangular in shape or 1019 m^2 if elliptical in shape. The average of these two values, 1000 m^2, will be used in this report. The sampling error for densities of fish derived in this manner is at least 5% (e.g., if the shoreline distance is 32 m rather than 35 m, then the rectangular area is 944 m^2 and the elliptical area is 947 m^2); other more significant sources of error include habitat selectivity (shallow areas could not be sampled) and avoidance due to boat disturbance.

A variety of coastal areas were sampled by beach seine during the summer period, 26 July-1 September (Fig. 9). Three general habitats were seined: mainland shoreline (n = 44 seine hauls), lagoon-side island shorelines (n = 11), and oceanside island shorelines (n = 8).

Pole Seine

Fourhorn sculpin young-of-the-year were sampled at three distances (0-2 m, 3-5 m, 10-12 m) from the lagoon shoreline of Pingok Island on 3 August 1977. A total of 17 plots, each approximately 20 m^2 (2 x 10 m),

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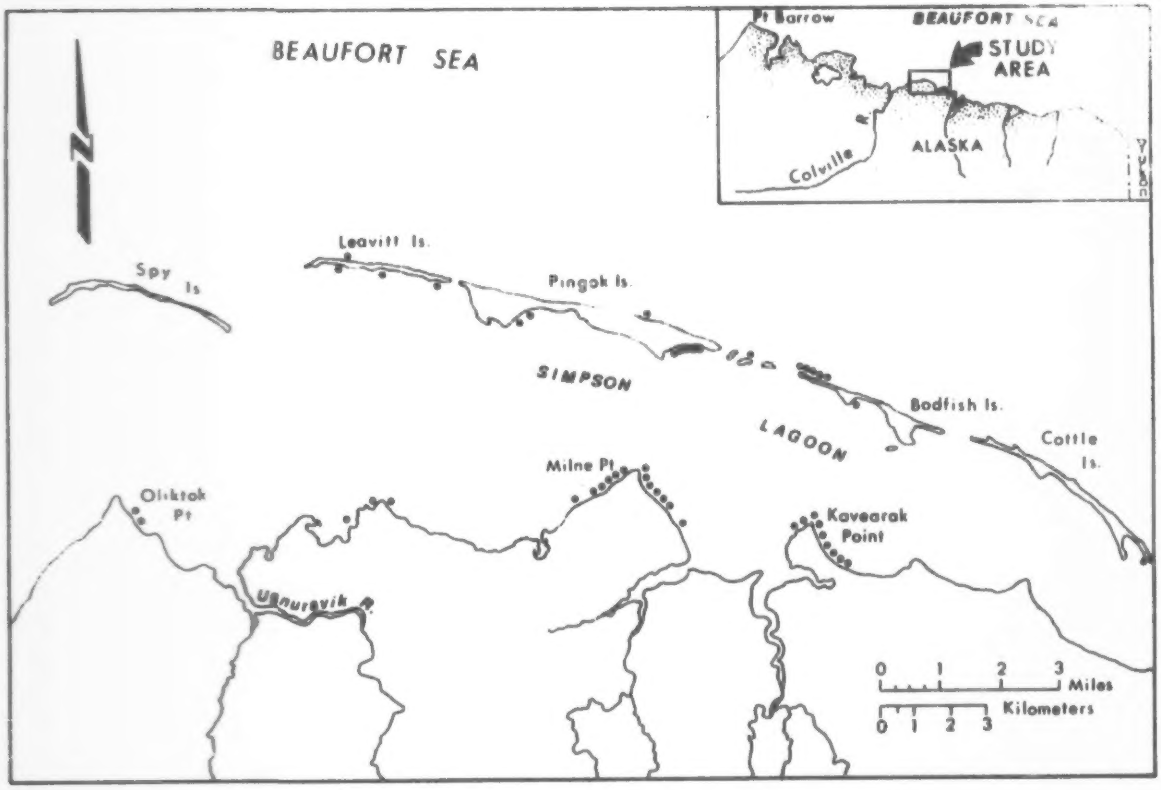
BEAUFORT SEA
Pt Barrow
BEAUFORT SEA
STUDY AREA
ALASKA
Colville R
Leavitt Is.
Spy Is
Pingok Is.
SIMPSON
LAGOON
Bodfish Is.
Cottle Is.
Milne Pt
Oliktok Pt
Kavearak Point
Ugnuravik R.
0 1 2 3 Miles
0 1 2 3 Kilometers

Figure 9. Sites sampled with a 91.4 m beach seine, 26 July-1 September, 1978. Symbols at Milne and Kavearak Points represent one or more sampling efforts.

was sampled with a 3.1 m (10 ft) pole seine. Most plots were seined once; however, repeat seine hauls in five plots showed that the first sweep collected an average of 75% of the fish present; therefore, this correction factor was applied to the data.

Fish Tagging

During the summers of 1977, 1978 and 1979, 6412 fish were tagged in Simpson Lagoon. Large anadromous fish (generally > 250 mm) were tagged with Floy dart tags. Small marine and anadromous fish (generally 100-250 mm) were tagged with metal opercular tags. Most were caught in the Milne Point fyke net, measured, tagged and released immediately. No mortality was observed among over 400 tagged fish kept in a pen for 1-7 days.

Other Methods

Other methods were also used to sample fish or otherwise obtain information but none was as successful as any of the previously described gear. Brief descriptions of other sampling efforts which proved unsuitable may be of interest.

1. SCUBA diving. In both 1977 and 1978, divers swam underwater transects about every two weeks at most sampling stations (Fig. 1), principally for invertebrate studies. Although we had hoped to study fish distribution and behavior in this manner, few fish were sighted. In 65 20-min dives, a total of four fourhorn sculpins and one arctic flounder were observed. Poor visibility (often <1 m), low fish densities, and avoidance behavior of fish probably account for the dearth of sightings.
2. Aerial surveys. Some observers report sighting fish during aerial surveys of arctic coastal waters; however, fisheries biologists who looked for fish during five aerial surveys flown at 30 m ASL and 160 km/h over the study area saw none. These were fixed-wing surveys flown over nearshore and offshore areas between Harrison Bay and Flaxman Island. Turbid lagoon waters often obscured visibility, although waters were clear in offshore areas and in shore leads during early summer.

3. Otter trawl. A 4.9-m otter trawl was used in 1977 to sample invertebrates. Only 10 fish were caught in 79 tows. Low catches probably resulted from slow trawling speeds and boat disturbance in shallow (1-2 m) waters.

4. Purse seine. A large purse seine (3.7 x 183 m) was tested in open lagoon waters. Four men set the net in calm water at Station 3 on 29 July 1978; no fish were caught. It quickly became apparent that it was not practical to work a net this size with the small boats available (17' Boston Whaler, 15' Zodiac).

5. Short-term fish release experiments. Two field experiments are briefly described because they illustrate experimental design problems in studies of fish movements. On 15 July 1978, 393 tagged anadromous fish (mostly ciscoes) were released after being retained 1-7 days in a holding pen at Milne Point. A gill net was set up at Kavearak Point (located 5 km east of the release point) to intercept those fish during the next 24 h (the fish had been traveling eastward when captured and it was presumed most would continue in that direction). Surprisingly, not one tagged fish was recaptured although previous tagging studies (Doxey 1977) have shown that some fish could easily traverse this distance in the allotted time.

   Results from a second experiment suggest one reason why the fish were not captured. In this experiment, individual fish were followed after release to determine their swimming speed and behavior. A 3.8 cm fishing bobber, attached by monofilament line and hook to the posterior base of the dorsal fin, was visible to observers following behind the fish in a two-man kayak. Six fish (3 arctic char, 2 least cisco, 1 arctic cisco) were each tracked for 2-3 h. Though this experiment was discontinued due to weather and logistical difficulties, it showed that the initial response of five fish was to head immediately for the deeper waters of the lagoon center (the sixth fish swam nearer the shore). The average swimming rate of these fish, 34 km/day, was considered to be more an escape response rather than a typical rate of movement for feeding fish.

Winter Methodology

Under-ice sampling programs were conducted in the Colville Delta (April-May 1978) and at several nearshore sites between the Colville Delta and Narwhal Island (November 1978, February and March-April 1979). Locations of sampling sites are indicated in Figs. 6 and 7.

Because of difficulties in collecting fish in ice-covered areas, a variety of nets was used during winter studies. Nets were set at the bottom of the water-column to avoid freezing with surface ice. Details of net types and time fished are presented in Tables 2 and 3. The overall winter sampling effort in coastal waters was extensive:

Gear	Days Fished
gill nets	225
fyke nets	47
minnow traps	14
trammel nets	10
box trap	1

A fathometer (Raytheon Model FR-450W) was also tested but gave limited success in detecting fish distribution and abundance.

Estimation of Daily Ration

To determine the effect of fish predation on epibenthic food resources, it is first necessary to estimate the amount of food ingested by fish each day (daily ration). In this study, the daily ration of arctic cod was calculated by determining the proportion of the day that the cod spend feeding, the amount of food in their stomachs at various times of day, and the rate at which food is passed through their stomachs (evacuation rate).

Stomach Evacuation Rate

The evacuation rate of food from stomachs of arctic cod was determined by placing freshly-caught fish in a food-free environment and then withdrawing samples of these fish at timed intervals to see how much food remained in the stomachs. The sample of arctic cod was caught in the previously-described fyke net from 10:00-13:00 ADT on 20 August 1978. The fish were placed in a large, fine-mesh holding pen (2 x 2 x 1.2 m deep; 0.8 mm mesh) located in the lagoon at the fyke net site. Samples of 18-20 fish were taken 0, 2, 4, 7.5 and 20.5 h after removal from the fyke net and dissected within one hour. Stomachs were

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Table 3. Sampling dates and gear used during winter surveys. Descriptions of sampling gear are given in Table 2. All net sets were bottom sets.

Sampling Period	Station (see Fig. 6, 7)	Net Used (Table 2)	Depth (m)		Dates Fished	Total Days
			Ice	Water		
April-May 1978	Colville A	Gill Net 5	2	1.5-4.5	9-20 April	13
	Colville B	Gill Net 5	2	10.7	9 April-22 May	44
November 1978	Thetis Island	Gill Net 5	0.7	3.0	9-14 November	5
		Gill Net 2			9-16 November	7
	Simpson Lagoon	Gill Net 2	0.7	2.4	4-15 November	12
		Gill Net 3			4-15 November	12
	Boulder Patch	Gill Net 2	0.7	5.8	5-10 November, 14-16 Nov.	7
		Gill Net 3			5-16 November	11
	Narwhal Island	Box Trap	0.7	12.1	3-4 November	1
		Minnow/Amphipod Trap			4-5 November	1
February 1979	Thetis Island	Gill Net 5	1.6	2.1	18-28 February	10
		Gill Net 4			18-28 February	10
	Simpson Lagoon	Gill Net 5	1.6	1.2	11-14 February	3
		Gill Net 2			12-14 February	2
		Gill Net 4			24-26 February	2
	Boulder Patch	Gill Net 4	1.6	4.9	14-15 February	1
		Gill Net 5			14-15 February	1
		Under-ice Fyke			15-27 February	12
	Narwhal Island	Gill Net 4	1.6	10.6	19-27 February	8
		Trammel Net			19-27 February	8
March 1979	Thetis Island	Gill Net 4			1 March-1 April	31
		Gill Net 5			1-20 March	19
April-May 1979	Thetis Island	Gill Net 2	1.9	1.7	3-7 May	4
		Gill Net 4			3-11 May	8
		Minnow/Amphipod Trap			3-7 May	4
		Fathometer			8-9 May	1
	Simpson Lagoon	Fyke Net #2	1.7	0.5	4-14 May	10
		Minnow/Amphipod Trap			1-6 May	5
	Boulder Patch	Gill Net 4	-	-	29 April-2 May	3
		Fyke Net #1			29 April-13 May	15
		Minnow/Amphipod Trap			4-8 May	4
		Fathometer			7-8 May	1
	Narwhal Island	Gill Net 4	1.9	10.0	30 April-2 May	2
		Trammel Net			30 April-2 May	2
		Fyke Net			2 May-12 May	10
	East Spy	Gill Net 4	1.8	3.3	8-12 May	4
		Fathometer			9-10 May	1
	West Spy	Gill Net 4	-	-	8-14 May	6

preserved in 10% formalin and contents were later weighed on a Mettler balance. The errors in weights of stomach contents resulting from formalin preservation and the time delay (6 wks) between collection and weighing are not known but are presumably consistent among samples since all samples were treated similarly. Lagoon water temperatures and salinities varied slightly during the course of this experiment (4.5-6.5°C, 24-26 ppt).

Feeding Periodicity

To determine whether arctic cod fed continuously or at particular times during the day or night, fish samples were collected from the lagoon at intervals over a 24-h period and their stomach contents inspected. The experiment was conducted at Milne Point where specimens were caught by beach seine or fyke net operating for short periods. On 23-24 August 1978, 10-15 arctic cod were collected at approximately 5-h intervals: 10:00, 15:00, 19:00-20:00, 24:00-01:00, 06:00-08:00 ADT. As the experiment progressed, the rate of catch decreased, presumably because few cod were in the area. Consequently, later in the sampling period more effort and time were required to catch at least 10 fish. The experiment ended when no cod were caught during the last sampling period at 11:00-13:00 on 24 August; the cod had vacated the area. Therefore, data acquired on two earlier dates (20 August 1978 at 10:00-13:00 and 21 August 1978 at 10:00 h) were included to supplement the analysis of feeding periodicity. The 20 August data were the t = 0 h data from the food evacuation rate experiment; the 21 August data were from the first attempt at a feeding periodicity experiment, which was aborted when rough waters hindered sampling efforts. Stomach fullness data from all dates were obtained in a similar fashion. Lagoon water temperatures and salinities were similar during all sampling periods: 20 August (6.5°C, 25 ppt), 21 August (4.5°C, 25 ppt), 23-24 August (4.5-5.0°C, 25-26 ppt).

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Physical and Chemical Measurements

Water temperature, salinity, dissolved oxygen and turbidity were measured daily 80 m from shore at Station 1, where the fyke net was operated, and at approximately 10-day intervals at other stations during both open-water seasons. Sampling instruments used in 1977 included a YSI-33 Salinity/Conductivity Meter (salinity, temperature), Hach Model 2100A Turbidimeter (turbidity) and Hach Portable Oxygen Determination Kit (dissolved oxygen). In 1978, equipment included a Hydro Lab Meter (temperature, conductivity) and DRT-15 Turbidimeter by H.F. Instruments. Turbidity is measured in nephelometric turbidity units (NTU).

Laboratory Analysis of Fish

Samples of fish were routinely collected for diet studies and life-history analyses. Abundant size classes of fish were generally sampled, but efforts were made to collect a complete size range of fish present, so uncommon sizes of fish were sampled when encountered.

Fish were examined in the field laboratory within 24 h after their capture. Laboratory analysis included determination of fork or total length to the nearest millimeter, weight to the nearest gram, sex and maturity. Based on a field evaluation of reproductive condition, and aided by measurements of egg sizes or testes weights, fish were classified as "immature" (have never spawned), "mature green" or "mature spawner" (would have spawned in the year of capture), or "mature non-spawner" (had spawned previously but would not spawn again in the year of capture). For some species, the assessment of reproductive status was partially subjective as noted by Craig and Mann (1974); criteria for these assessments are described in fish life-history sections of this report.

Fish ages were determined by analysis of otoliths according to the criteria and methods of Nordeng (1961) and Williams and Bedford (1974). Although otoliths are a preferred method for aging northern or slow-growing fish species (e.g. Craig and Mann 1974; Mann 1974), the annuli are occasionally difficult to interpret (Yole 1975; Beamish 1979).

As an indicator of fish condition, the total weight of fat on the digestive tract of each of 33 arctic cisco was determined in the following manner. Intestinal fat (IF) was weighed together with the pyloric caeca (PC), which held a considerable amount of fat (PCF). PC weights were estimated by regressing IF against IF + PC + PCF. On the assumption that PCF would be zero when IF is zero, an extrapolation indicated that PC weights were about 7 g for fish under 350 g and 8 g for larger fish. This weight was subtracted from the initial figure (IF + PC + PCF) to give weight of fat only.

Parasites

A preliminary examination of fish parasites was made. Five samples of 21-25 arctic cisco were collected--two samples from under the ice in the Colville Delta (November 1976 and 1977) and three samples during the open-water season in Simpson Lagoon (30 June, 27 July and 2 September 1977). These arctic ciscoes averaged 345 mm fork length (range 275-385, SD = 21) and 551 g weight (range 265-801g, SD = 136). The gills and viscera were removed and preserved in 10% formalin and later examined for the presence of parasites. Condition factors for these fish were determined by the equation:

$$C = \frac{\text{weight (g)}}{\text{length (cm)}^3}$$

Food Habits

Summer and winter diets of fish in coastal waters were examined. For each selected species and sampling period approximately 30 specimens were collected for analysis of stomach contents. Locations and dates of collections were as follows:

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Date	Location Simpson Lagoon	 Colville Delta	 Thetis Is.- Narwhal Is.
1977			
Early summer	19 June-25 July		
Mid-summer	3-19 August		
Late summer	30 Aug-18 Sept.		
1978			
Late winter		8 April-22 May	
Early winter	26 June-3 July		
Mid-summer	16-30 July		
Late summer	17 Aug-4 July		
Early winter			5-16 May
Mid-winter			17-27 Feb.
Late winter			7 Mar-14 May
1979			
Mid-summer	17-28 July		

The timing of collections depended partly on the availability of specimens.

Fish used in diet studies were collected by gillnet (87%) and fyke net (13%). Fish caught in fyke nets were used only when sample sizes from gill nets were low since those caught in fyke nets may have fed upon invertebrates attracted to or caught by the fyke net. For each species, the fish examined were generally from the most common size-class present at the time of sampling (Table 18). However, we exercised some selection of specimens to ensure that similar size-classes were studied throughout the summer months.

Fish stomachs were preserved separately in formalin and later analyzed in the laboratory. Identifiable items were counted, measured and weighed according to the methods described by Griffiths and Dillinger (1980). One change in methods should be noted--weights of major prey species in the 1978 and 1979 samples were determined by "reconstructing" their weight prior to partial digestion by the fish. This was accomplished by measuring a selected part of the organism and then calculating its total weight when ingested from length relationships between the part and the total organism, and from the weight-length relationships for the species. Weights of earlier (1977) collections were determined by directly weighing all identifiable specimens and fragments for each species. Limitations and biases of these techniques are discussed by Griffiths and Dillinger (1980).

The degree of food overlap between fish species was determined by the modified Morisita index (Horn 1966):

$$C = \frac{2 \sum_{i=1}^{S} X_i Y_i}{\sum_{i=1}^{S} X_i^2 + \sum_{i=1}^{S} Y_i^2}$$

where S is the total number of food categories, and X_i and Y_i are the proportions of food item in the diets of species X and Y, respectively. The index C varies from 0, when the diets have no food items in common, to 1, when the diets are identical in kinds and proportions of food items. A value of 0.6 or greater is assumed to indicate a significant overlap (Zaret and Rand 1971).

GENERAL RESULTS

The results of the Simpson Lagoon program are presented in two sections. The first section describes how fish use nearshore waters--habitat utilization and trophic relationships are examined. The second section presents additional life-history data for each of the fishes using the study area.

Fish Populations in Simpson Lagoon

Species Composition

During summer (1977 and 1978) and winter (1978 and 1979) sampling periods, a total of 22 fish species were caught in Simpson Lagoon and nearby coastal waters. These fishes are listed below according to their principal life-history pattern:

Anadromous Species

- arctic char (*Salvelinus alpinus*)
- arctic cisco (*Coregonus autumnalis*)
- least cisco (*C. sardinella*)
- Bering cisco (*C. laurettae*)
- broad whitefish (*C. nasus*)
- humpback whitefish (*C. pidschian*)
- boreal smelt (*Osmerus eperlanus*)
- ninespine stickleback (*Pungitius pungitius*)
- pink salmon (*Oncorhynchus gorbusca*)
- chum salmon (*O. keta*)
- threespine stickleback (*Gasterosteus aculeatus*)

Marine Species

- arctic cod (*Boreogadus saida*)
- fourhorn sculpin (*Myoxocephalus quadricornis*)
- arctic flounder (*Liopsetta glacialis*)
- saffron cod (*Eleginus gracilis*)
- capelin (*Mallotus villosus*)
- Pacific herring (*Clupea harengus*)
- snailfish (*Liparus* sp.)
- sculpin (*Myoxocephalus* sp.)
- Pacific sand lance (*Ammodytes hexapterus*)

Freshwater Species

- round whitefish (*Prosopium cylindraceum*)
- grayling (*Thymallus arcticus*)

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Based on the variety of sampling methods used and the thorough sampling efforts in time and space (see METHODS), it is felt that this list represents virtually all fishes utilizing the lagoon during 1977 and 1978. Almost 200,000 fish were caught during the course of this study (all but subsamples were released alive). Totals of 11,173 fish were taken during the 1977 open-water season, 179,937 fish during the 1978 open-water season, and 2734 fish during winter studies.

Three additional species were caught outside Simpson Lagoon: sockeye salmon (*Oncorhynchus nerka*), spotted snailfish (*Liparus callyodon*) and wattled eelpout (*Lycodes palearis*). The sockeye was caught in the Colville River and the two other marine fishes were collected seaward of Pingok Island.

Relative Abundance

Summer. Although 22 fish species were caught in Simpson Lagoon, five species accounted for over 91 and 98% of all fish caught during the summers of 1977 and 1978, respectively. Two marine species (arctic cod, fourhorn sculpin) were the numerical dominants in the lagoon, and three anadromous species (arctic cisco, least cisco, arctic char) were the next most abundant. These species also characterize the fish fauna of nearshore waters along most of the Beaufort Sea coastline (Craig and McCart 1976; U.S. Dept. Commerce and Dept. Interior 1978).

The relative abundance of fishes taken in Simpson Lagoon varies according to method of capture (Table 4). Each type of gear commonly used to catch fish is strongly biased in terms of both the species and the sizes of fish caught. In 1977, for example, the Faber net collected ichthyoplankton, the fyke net caught primarily small and/or marine fish, and gill nets caught primarily large anadromous fish.

The fyke net data are of particular interest because the majority of fish caught by this method were small arctic cod, fourhorn sculpin and arctic cisco. These data and the results of Bendock (1977) from Prudhoe Bay show that small fish are substantially more common in nearshore Beaufort Sea waters than indicated by earlier studies that relied on data obtained by gill nets (reviewed by Craig and McCart 1976).

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Table 4. Relative abundance of fish caught during the open-water season by different methods in Simpson Lagoon.

Fish Species	1977 Gill Net %	1977 Fyke Net %	1977 Faber Net %	1978 Beach Seine %	1978 Fyke Net %
Arctic cod	0.1	7.6	83.1	7.6	77.9
Fourhorn sculpin	9.2	69.6	0	20.9	17.9
Arctic cisco	56.3	14.7	0	16.7	0.8
Least cisco	11.6	2.3	0	48.2	1.2
Arctic char	14.2	3.8	0	3.6	0.9
Broad whitefish	3.8	0.1	0	1.1	0.2
Humpback whitefish	2.2	0	0	0	*
Arctic flounder	0.4	1.3	0	0.7	0.3
Boreal smelt	0	0.2	0	0.7	0.6
Saffron cod	0	0	0	0	0.3
Bering cisco	1.0	0	0	0	*
Capelin	1.0	*	0	0	*
Pink salmon	0	0	0	0.2	0.1
Ninespine stickleback	0	0.2	0	0	*
Pacific herring	0	0	0	0	*
Snailfish sp.	0	0.1	16.9	0.2	*
Grayling	0	0	0	0	*
Chum salmon	0	0	0	0	*
Sculpin sp.	0	0	*	0.2	0
Three-spine stickleback	0	0	0	0	*
Pacific sand lance	0	0	0	0	*
No. fish caught	781	10,026	366	450	179,487
% anadromous fish	89	21	0	70	3

*<0.05%

Fish numbers and composition in Simpson Lagoon changed markedly between the two years of study. In 1978, all species found in 1977 were found again and eight additional fish species were encountered. Three of these species are outside their reported ranges by several hundred kilometers; the threespine stickleback and sockeye salmon have not been recorded previously in Beaufort Sea waters, and the Pacific sand lance has apparently not been collected between the Chukchi Sea and Herschel Island, Yukon Territory (McAllister 1962; McPhail and Lindsey 1970; Hart 1973; Scott and Crossman 1973). There was also a small run of pink salmon in Simpson Lagoon during 1978, whereas during 1977 no salmon were caught.

The tremendous numbers of arctic cod (estimated in the millions) that entered Simpson Lagoon in mid-August of 1978 constituted the most important difference between years. The actual 1978 catch of 139,792 arctic cod was approximately 13 times larger than the total number of all fish caught during the previous summer. In fact, on four separate occasions in 1978, the daily catch of arctic cod exceeded the total 1977 catch. Arctic cod were also present in the lagoon in 1977, but their numbers were low (n = 767 in the fyke net). Between-year differences in sampling methods undoubtedly affected the size and species composition of the catch. However, the almost 200-fold increase in numbers of arctic cod caught in 1978, and their overwhelming dominance of the 1978 species composition in fyke-net catches from the lagoon (from 8% in 1977 to 78% in 1978), demonstrate that fish numbers and relative abundance in the lagoon-barrier island ecosystem may fluctuate dramatically from year to year.

If the numbers of arctic cod in 1978 are excluded from the catch records, and if only the data obtained from 25 July to 22 September (the period that the 1977 fyke net operated) are considered, then the relative abundances of the major species become:

Species	1977 %	1978 %
arctic cod	-	-
fourhorn sculpin	75	86
arctic cisco	16	2
least cisco	2	3
arctic char	4	2
other species	2	7
Total number of fish caught	9,259	34,582

It appears that proportions of most major species other than arctic cod and arctic cisco were fairly similar in the two years. Catches in both years indicate that fourhorn sculpin are a major component of this nearshore ecosystem. Numbers of fish were much higher in 1978, but a direct comparison between years is questionable due to several differences in methodology (e.g., changes in fyke net location and improved efficiency in 1978--see METHODS).

Winter. In winter, species composition changed sharply from the summer pattern. Virtually all anadromous species disappeared from the nearshore marine environment, leaving 5 marine species and 1 anadromous species (boreal smelt):

Species	% Composition
boreal smelt	57
fourhorn sculpin	37
arctic cod	4
saffron cod	1
snailfish	0.5
arctic flounder	0.4
Total number caught	2734

Two species, boreal smelt and fourhorn sculpin, accounted for 94% of the winter catch. Arctic cod may be under-represented in these figures because of gear selectivity (see 'Additional Life-History Data for Fishes').

Biomass

When lagoon populations of fish are described in terms if biomass rather than numbers of individuals, the dominance of the system by marine species is less pronounced. The principal marine species, arctic cod and fourhorn sculpin, are small fish whose total biomass is much less impressive than their total numbers. For example, one large arctic cisco is the weight equivalent of 60-70 average arctic cod.

To obtain biomass estimates for fish in Simpson Lagoon, it was first necessary to estimate the average weight of each species taken. Fyke net data were used to estimate mean weights because fish caught in beach seines were not weighed and gill nets selectively caught large fish. For arctic cod, a random sample of 108 individuals taken from the fyke net in 1978 were weighed to provide an average. For the remaining species, the average weight was estimated from sub-samples of the 1978 fyke catches; these specimens had been selected for life-history analysis rather than as an unbiased representation of fish sizes taken by fyke net, so the resultant average weight may be somewhat biased. The average weights obtained in this manner are listed below for species that comprised more than 1% of the total fish biomass.

Species	Mean Weight (g)
arctic cod	10
fourhorn sculpin	45
arctic cisco	280
least cisco	270
arctic char	760
broad whitefish	700
humpback whitefish	700
arctic flounder	140
saffron cod	35
pink salmon	1010

The above means were multiplied by the number of each species caught during the open-water season of 1978 in fyke nets to provide an estimate of the relative biomass of each species.

Biomass calculations demonstrate that, during the open-water season, anadromous species are more important as consumers than might have been deduced based on their relative abundance (Fig. 10). During the summer

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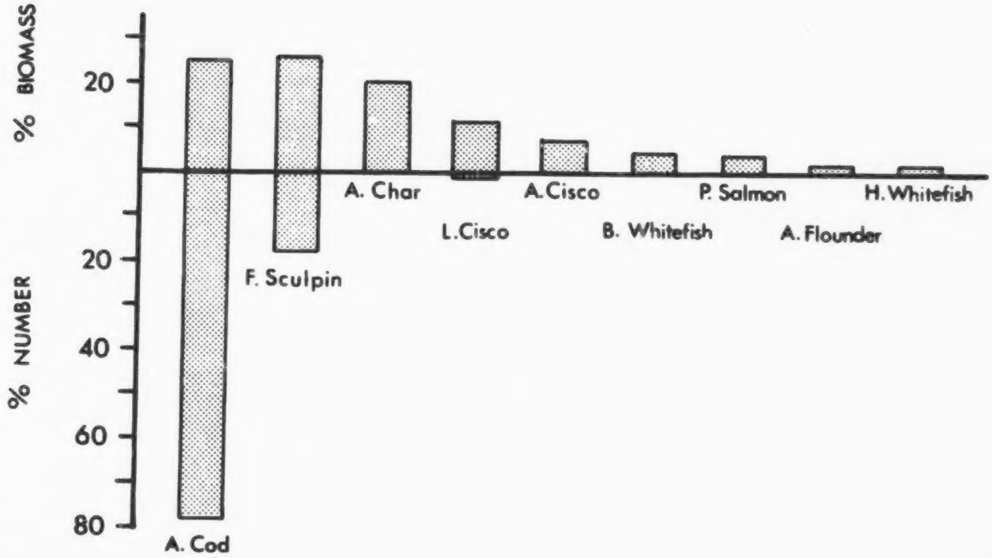

Figure 10. Comparison of relative abundance and biomass for the 1978 fyke net catch (open-water season). Species comprising less than 1% of the total biomass are not included. For the nine species listed, the total number of fish caught was 178,353 and the estimated total biomass caught was 5405 kg.

of 1978, anadromous fish accounted for almost half (46%) of the estimated total fish biomass but only 3% of the estimated total number. This difference reflects the relatively large sizes and small numbers of anadromous fish and the small sizes and large numbers of marine fish. Three out of every four fish collected in the lagoon were arctic cod, but this species accounted for only 26% of the total fish biomass.

A similar situation existed during 1977, when anadromous fish comprised 46% of the total biomass and 21% of the numbers captured in the fyke net. In that year, the fourhorn sculpin was the most commonly captured species (70% of catch) but because of the small size of individuals, accounted for a lower proportion of the biomass (49% of total biomass).

Habitat Utilization

Two prominent trends in the spatial distribution of anadromous fish during the open-water season were evident: (1) most fish were found in nearshore brackish waters rather than offshore marine locations, and (2) within brackish waters, fish numbers were highest along shoreline edges, particularly the mainland shoreline. These generalizations are not necessarily valid for marine fishes; the two most abundant species--fourhorn sculpin and arctic cod--are not restricted in distribution to nearshore waters.

Nearshore (Brackish Water) versus Offshore (Marine) Distribution

During the 1977 gill net program,far more fish were caught per unit effort in lagoon habitats than in marine habitats (Fig. 11, Table 5). This difference is even more apparent if the seaward shoreline of the barrier islands is considered to be a nearshore habitat. This shoreline may be flooded by lagoon waters when west winds push the lagoon water mass out through the gaps between the barrier islands. On a catch per unit effort basis, fish were 5-98 times more abundant at various nearshore stations than at the one offshore station. Nearshore catches ranged from a high of 39.2 fish/24 h (species combined, seasonal average) along the mainland shoreline to a low of 2.1 fish/24 h in the lagoon

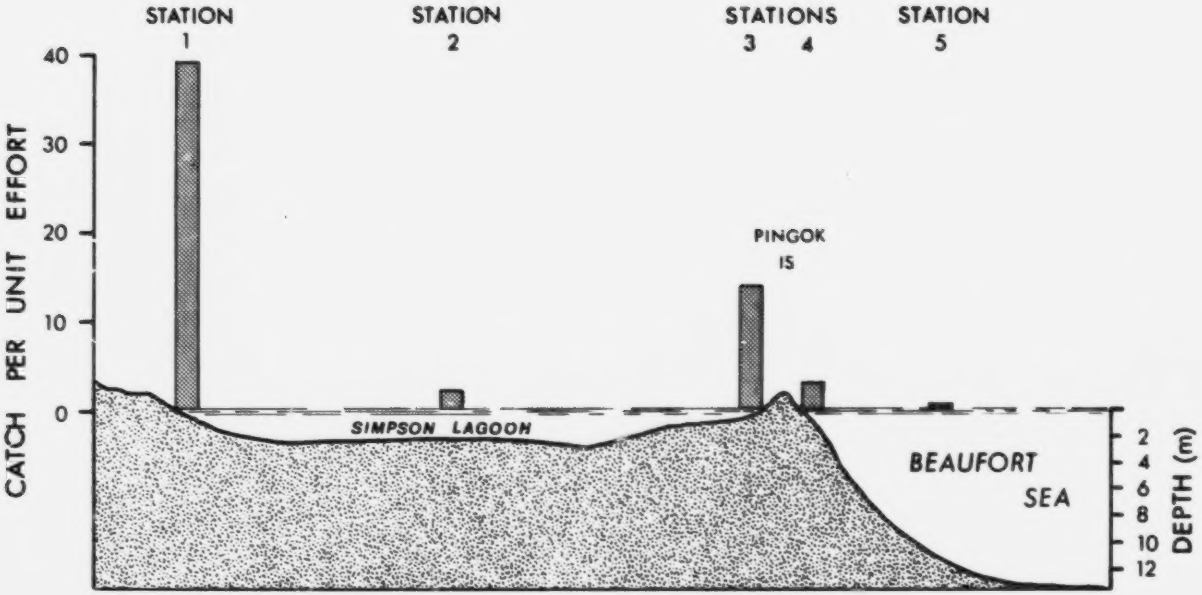

Figure 11. Cross-section of Simpson Lagoon study area showing relative numbers of fish caught at 5 sampling stations, 1977. Numbers of fish represent a seasonal average for combined species caught in a standardized 24-h gill net set.

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Table 5. Comparisons of gill net data at five sampling locations during the open-water season, 1977. (See Fig. 11 for locations.)

Fish Species	Seasonal Averages of Fish Caught Per 24-Hour Gill Net Set at Stations					Comparison of Stations 1-4 (Friedman test)
	1	2	3	4	5	
Arctic cisco	17	1.1	9	0.1	0	<0.02*
Least cisco	8.1	0	0.7	0	0	<0.01
Arctic char	5.9	0.4	3	2.1	0	<0.2
Fourhorn sculpin	3.4	0.5	0.8	1	0.1	<0.1
Broad whitefish	3	0	0	0	0	<0.02
Humpback whitefish	1.6	0	0	0	0	<0.01
Arctic flounder	0.2	0	0	0	0	<0.1
Capelin	0	0.1	0.8	0.1	0	<0.1
Snailfish	0	0	0.1	0	0.2	-
Arctic cod	0	0	0	0	0.1	-
All anadromous spp.	35.6	1.5	12.7	2.2	0	<0.01**
All marine spp.	3.6	0.6	1.7	1.1	0.4	<0.1
Totals	39.2	2.1	14.4	3.3	0.4	
No. Sets	10	10	10	7	7	
No. Days Fished	10	19	10	10	10.5	

* Friedman critical value test indicates that numbers of fish at station 1 are significantly greater than station 4 ($P < 0.01$).

**Station 1 > 2 and 1 > 4 at $P < 0.04$.

center. In contrast, the average catch in offshore gill nets was only 0.4 fish/24 h, and, significantly, no anadromous species were caught (Table 5).

In 1978, several tows with an otter trawl were made 1.6-7.2 km offshore and, again, marine species were the only fish caught (Table 6). Other fisheries studies have also documented the absence or very low densities of anadromous fish in offshore Beaufort Sea waters, although the overall sampling effort in this zone has been low (McAllister 1962; Mann 1974; Griffiths et al. 1975, 1977; Percy 1975; Jones and DenBeste 1977; Frost et al. 1978; Galbraith and Hunter 1979; C. Broad, pers. comm.; K. Tarbox, pers. comm.). Arctic anadromous fish remain in nearshore habitats, foregoing the impressive oceanic migrations of some non-arctic salmonids.

Numbers of fish collected in plankton trawls were also greater inside the lagoon than offshore, but the differences were not statistically significant in either 1977 or 1978 (Table 7). The extreme variability in catch records indicate the need for a more extensive sampling program before the general significance of lagoon habitats for planktonic fish is known.

The "Edge Effect"

Within the nearshore brackish water region, it is apparent that fish are not uniformly distributed but are far more abundant along mainland and island shorelines than in the lagoon center (Fig. 11). Seasonal-averaged catches along the mainland shoreline were 19 times greater than in the lagoon center. This finding is similar to that obtained in Kaktovik Lagoon where three paired shoreline gill nets caught 30 times more fish than three mid-lagoon sets (Griffiths et al. 1977). Kendel et al. (1975) observed the same pattern along the Yukon coastline.

Although fish catches along all shorelines in the Simpson Lagoon study area were higher than in open-water areas, the mainland shoreline was used more extensively and by more species of fish than were island shorelines (Fig. 11, Table 5). In statistical comparisons of the numbers of fish at the four nearshore stations, the only sampling periods

Table 6. Fish caught by otter trawl in marine waters offshore from Pingok Island, 13 August 1978.

	No. Fish/Trawl-Hour			
	Distance Offshore (km)			
Fish	1.6	3.2	4.8	7.2
Arctic cod	6	6	21	14
Fourhorn sculpin	10	10	9	14
Spotted snailfish*	14	20	14	15
Wattled eelpout**	0	0	0	1
Water Depth (m)	10	12	15	14
Actual Trawl Time (h)	0.5	0.5	1	1

* *Liparis callyodon*

***Lycodes palearis*

Table 7. Seasonal densities of young-of-the-year arctic cod[1,2] (1977) and combined planktonic species[3,4] (1978) collected by Faber Net.

1977 Sampling Dates	No. Arctic Cod/1000 m^3 At Stations (1977)				1978 Sampling Dates	Total No. Fish/1000 m^3 At Stations (1978)				
	1	2	3	5		2	3	4	6	7
11 July	-	6	0	-	10 July	98	22	2	10	-
22 July	-	50	0	0	22 July	54	14	12	15	-
31 July	-	0	31	0	4 August	5	0	0	-	5
14 August	-	855	694	0	17 August	0	0	16	-	8
25 August	0	0	0	0	30 August	0	0	16	-	0
5 September	0	0	6	0	14 September	0	0	0	-	7
14 September	0	0	99	62	23 September	0	0	0	0	-
Means	0	130	119	10		22	5	7	12	5

[1] 83% of collection was arctic cod (Table 4).

[2] Paired t-test on averaged data for stations 2 and 3 vs station 5 gave t = 1.05, d.f. = 5, $P > 0.1$.

[3] Species composition in subsample (n = 52): 61% cottidae, 25% gadidae, 14% liparidae.

[4] Paired t-test on averaged data for stations 2, 3 and 4 vs stations 6 and 7 gave t = 1.17, d.f. = 5, $P > 0.5$.

considered were those when all four stations were sampled at approximately the same time: 14-16 and 25-29 July, 3-13 and 18-20 August, 30 August-8 September, and 6-7 September 1977. This procedure minimizes the potential confounding of seasonal and geographic effects. Results of this comparison showed that, for each species tested except fourhorn sculpin, numbers of fish at nearshore stations 1-4 were significantly different (Table 5), although only a single difference among stations could be determined using critical values based on Friedman rank sums (Hollander and Wolfe 1973). However, an inspection of Table 5 shows that species were consistently most abundant at Station 1, and when all anadromous fish were combined, there were significantly more fish at Station 1 than at either Station 2 or 4 ($P < 0.04$)

Data obtained in 1978 by different sampling gear (91.4 m beach seine) followed the same pattern shown in Fig. 11. Fish densities along the mainland shoreline (0.0095 fish/m^2, species combined) were far greater than at other locations, averaging 3.5 and 24 times greater than densities along the lagoon and ocean sides of the barrier islands, respectively (Table 8). The relative numbers of fish caught along the three shoreline habitats were very similar during the two years of study, especially if small fish (i.e., char and whitefish <200 mm, sculpin <100 mm) are excluded from the 1978 beach seine data (these size classes of small fish are not often caught by gill nets):

	Relative Number Caught		
Method	Mainland Shore	Island (Lagoonside)	Island (Oceanside)
1. gillnet (1977)	12	4	1
2. beach seine (1978) ("large" fish only)	18	6	1
3. beach seine (1978) (all fish)	24	6.5	1

Data obtained by fyke nets (which tended to catch smaller fish than gill nets in 1977) corroborated the difference in fish catches between mainland and island shorelines (Table 9). In 1977, the average catches in 24 h were 160 fish at the mainland site and 104 fish at the island

Table 8. Beach seine data for mainland and Barrier Island shorelines during the open-water season, 1978.

	Seasonal Averages of Fish/Seine Haul		
Fish	Mainland	Island Lagoonside	Island Oceanside
Least cisco	4.9 (20)*	0.1 (1)	-
Fourhorn sculpin	2.0 (17)	0.4 (3)	0.1 (1)
Arctic cisco	1.4 (16)	1.2 (3)	-
Arctic cod	0.8 (6)	-	-
Arctic char	0.1 (3)	0.9 (4)	0.3 (1)
Broad whitefish	0.1 (4)	-	-
Boreal smelt	0.1 (2)	-	-
Arctic flounder	0.1 (3)	-	-
Pink salmon	0.02 (1)	-	-
Sculpin sp.	0.02 (1)	-	-
Liparid sp.	-	0.1 (1)	-
All anadromous spp.	6.6	2.2	0.3
All marine spp.	2.9	0.5	0.1
Totals	9.5	2.6	0.4
Density (Fish/m^2)	0.0095	0.0027	0.0004
No. Seine Hauls	44	11	8

*Parentheses indicate number of seine hauls in which each species was caught.

Table 9. Comparison of fyke net data for mainland and Pingok Island sites, 8 August to 21 September 1977. During this period, nets were operated 36 days (mainland) and 30 days (island).

Fish	Mean Catch in Fyke Net/24 Hour: Mainland Shoreline (Station 1)	Mean Catch in Fyke Net/24 Hour: Island Shoreline (Station 3)	Paired Comparison (Wilcoxon test)
Fourhorn sculpin	92	94	$P \simeq 0.1$
Arctic cisco	36	6	$P < 0.001$
Arctic cod	15	4	$P < 0.01$
Arctic char	8	1	$P < 0.05$
Least cisco	5	0.03	$P < 0.01$
Arctic flounder	3	0.07	$P < 0.01$
Smelt	0.6	0.07	-
Ninespine stickleback	0.4	0.07	$P < 0.02$
Broad whitefish	0.3	0	$P < 0.05$
Snailfish	0.1	0.03	-
Capelin	0	0.07	-
All anadromous spp.	50	7	$P < 0.001$
All marine spp.	110	98	$P \simeq 0.07$
Total	160	105	
Daily Range	(2.626)	(0-810)	

site (lagoon side of Pingok Island). Numbers of most species were highest along the mainland shoreline, and these differences were statistically significant for all species compared except fourhorn sculpin (Table 9).

Thus, catches of both large fish (gill net and seine catches) and small fish (fyke net and seine catches) are higher along the mainland shoreline than anywhere else in the study area. This may be a reflection of the fact that the mainland shoreline is, on the average, warmer and less saline than other nearshore habitats (Figs. 2 and 3) (however, see discussion in 'Effects of Physical Factors').

Two notes of caution are necessary in regard to the above discussion. First, although fish are concentrated along the shoreline, the lagoon center probably accommodates as many fish because of its relatively large size. The following calculation illustrates this point. From Table 5, the average number of anadromous and marine fish caught in each meter of gill net (all nets in 1977 were 45.7 m long) can be determined for each station. These stations represent particular types of habitat (mainland edge, lagoon center, island edge), and the extent of each habitat can be estimated along a cross section of the lagoon from the mainland to Pingok Island. Using these sets of figures, the relative number of fish can be calculated for shoreline and lagoon center:

1977 Sta. No.	Habitat Type and Estimated Width Across Lagoon	No. Fish/m of gill net		Relative No. Fish in Habitat Type	
		anad.	marine	anad.	marine
1	mainland edge (100 m*)	0.78	0.08	78	8
2	lagoon center (4500 m)	0.03	0.01	135	45
3	island edge (100 m*)	0.28	0.04	28	4

*estimated on basis of Figure 13.

Although these calculations are rough, they show that a theoretical gill net set across the whole lagoon would catch 106 anadromous fish in shoreline habitats and 135 anadromous fish in the lagoon center. It appears, then, that the total number of anadromous fish in the lagoon center is similar to the total number of fish along the shoreline edges.

In contrast, marine fish are more abundant in the lagoon center than edges (45 fish vs 12 fish).

The second note of caution concerns the apparently greater importance of the mainland shoreline than the barrier island shoreline as a migration corridor. This difference may reflect the large distance (4-6 km) between the Pingok Island sampling site and the mainland coast. It is not known if densities of anadromous fish around barrier islands are a function of the distance of these islands from the mainland.

Affinity for the mainland shoreline varied among species, as previously noted by Bendock (1977). Least cisco, broad whitefish and humpback whitefish in Simpson Lagoon were not commonly taken anywhere but in the relatively warm and brackish waters along the mainland (Tables 5, 8 and 9). Arctic cisco and arctic char were distributed more widely and were commonly present along the lagoonside beaches of the barrier islands. Char were the most abundant anadromous fish along the seaward beaches of the barrier islands. Bendock (1977) reports that char have been caught as far offshore as Cross Island which is about 18 km offshore.

The fourhorn sculpin was distributed more evenly through the study area than were other species. Fyke net data (Table 9) showed sculpins to be equally abundant along mainland and barrier island (lagoonside) beaches; beach seines showed them to be most abundant along the mainland, although this difference was not statistically significant (2 x 3 contingency test, $\chi^2 = 2.30$, $P > 0.25$).

The Shoreline Corridor

Many fish travel parallel to the shoreline along a surprisingly narrow corridor. It is a common observation that gill nets attached to the shoreline catch many fish while nets set only 100 m seaward of the shoreline catch few fish (e.g., McAllister 1962). On some occasions the fish may even swim within a few meters of the shore. Griffiths et al. (1975:99) made the following observation at Nunaluk Lagoon, Yukon Territory (abridged and italics added from field notebook):

> On an unusually calm day in autumn (August 31, 1974), numerous schools of fish were observed moving eastward in shallow water (0.3 to 1.0 m) *about 1-5 m from the shoreline* adjacent to Nunaluk Spit. These schools were easily detected by small, V-shaped surface waves. At least 10 schools, all heading east, passed by in 30 min. Two of these schools were sampled by gill net; each was composed of 10 to 20 Arctic cisco and Arctic char. *Two additional schools were observed that were not adjacent to the shoreline; one was moving eastward about 300 m offshore, another came perpendicular to shore and turned east.*

Furniss (1975:37) also noted that in Prudhoe Bay large numbers of arctic char sometimes migrated "very close to the shore in extremely shallow water".

In 1978, the distribution of fish relative to distance from shore was examined by recording positions of fish caught in a 122 m gill net placed perpendicular to the shoreline. This long net was set with a 2-3 m gap between the net and the shoreline so that fish trying to avoid capture would not be funneled into the net at the shoreward end (see METHODS). The catch results show that, under certain circumstances, there is indeed a narrow band of fish adjacent to the shoreline. Although the specific factors involved are unknown, catches were greater close to shore under the following conditions: (1) the water was not exceptionally rough, and (2) the sampling location was at or near a prominent land projection into the lagoon (e.g., Milne Point or Kavearak Point), where water depths fell more rapidly than in embayments. Two examples are illustrated in Fig. 12.

The most convincing evidence of fish traveling next to the shore was recorded at the tip of Kavearak Point on 24 July 1978 in fairly clear water (3 NTU, or roughly 1 m visibility). On this occasion 50% of the 32 fish caught in the gill net were within 30 m of the shoreline and all were within 80 m. Only anadromous species were caught in this 3-h net set: 13 least cisco, 13 arctic char, 4 arctic cisco, 1 broad whitefish, and 1 humpback whitefish.

A second but less distinct example was encountered at the Milne Point (East) site, which was located on the eastern side of the point, 0.6 km southward of the tip. Here 80% of the fish caught during

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concentration of fourhorn sculpin, a marine species, near the mouth of the Colville River is not readily explained by any available information.

The data presented in Tables 10 and 11 very likely provide a biased representation of the abundance and distribution of arctic cod. Arctic cod, because of their shape, are often difficult to catch in gill nets. In November, nearly all of the cod captured in gill nets had advanced gonadal development in addition to full stomachs--the resultant obese condition was likely responsible for their capture. In February 1979 all of the arctic cod had apparently finished spawning, and no captures were made in gill nets. After November, two new experimental fishing systems, an under-ice fyke net and a trammel net were used at some locations (Table 3). The fyke nets were responsible for capturing nearly all cod, thus accounting for the relatively high catch per unit effort at the Boulder Patch station.

Saffron cod were also concentrated in the area of the Colville River mouth (Thetis Island station) in February. The appearance of some apparently mature fish in pre-spawning condition suggests that this area may be a spawning ground for this species.

Snailfish appeared in the under-ice fyke net catches at the Boulder Patch station in February 1979. Since this species is apparently vulnerable to capture only by this sampling method, we obtained no information about geographic or temporal patterns in its distribution or abundance. Snailfish were actively spawning in the area of the Boulder Patch station in February, as indicated by the attachment of their adhesive egg masses to under-ice sampling gear. The fact that they have demersal adhesive egg masses suggests that a solid substrate, as is common in the Boulder Patch area in the form of rocks and attached algae, may be a requirement for their spawning.

Effects of Physical Factors

Most nearshore fishes are tolerant of the widely fluctuating temperatures, salinities and turbidities common in Simpson Lagoon during the open-water season. For at least short periods of time, the fish are

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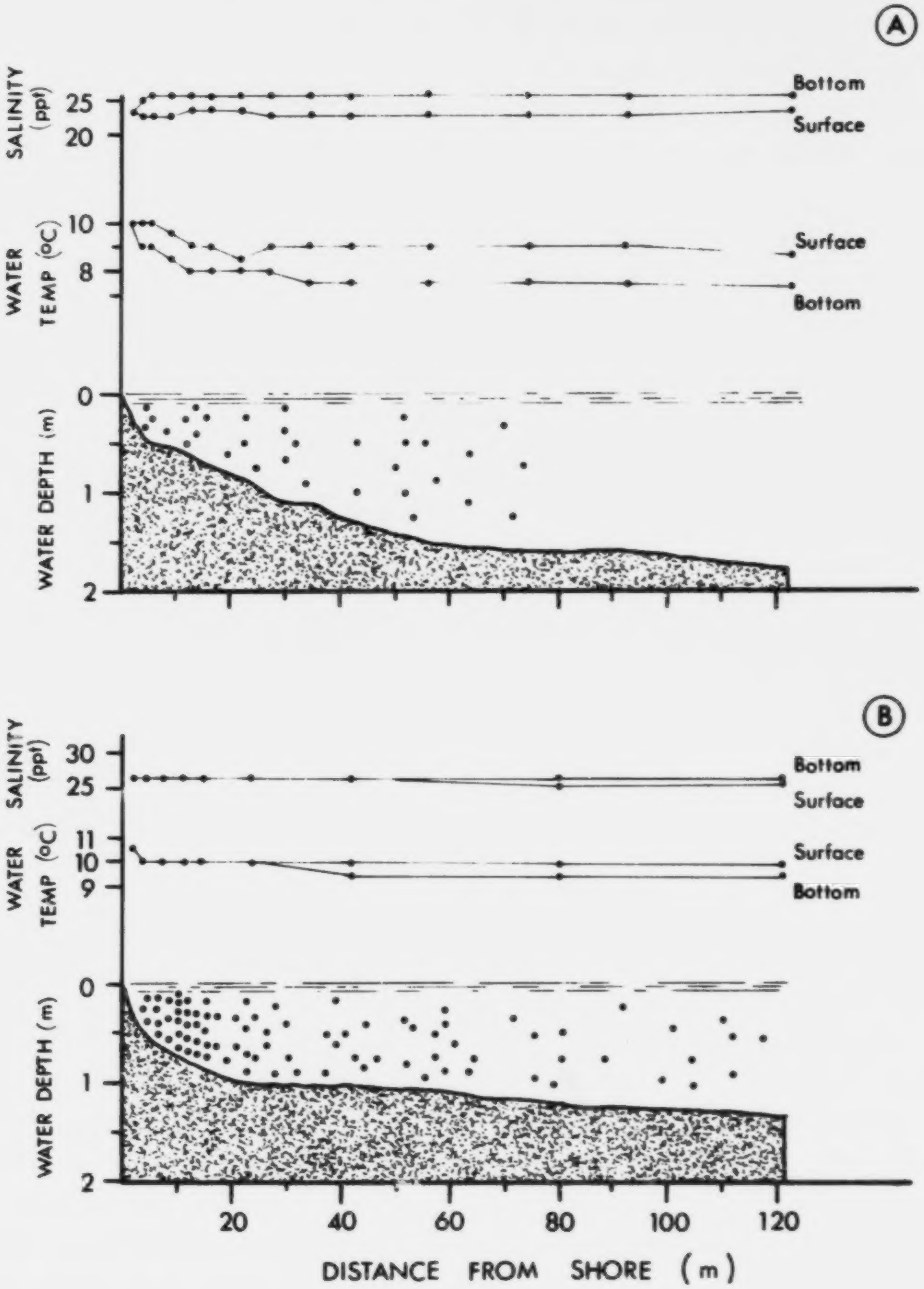

Figure 12. Shoreline distribution of fish at two sites: (A) Kavearak Point, 24 July 1978, 3 net-h; (B) Milne Point East, 29 July 1978, 4.5 net-h. Actual distributions of fish (dots) are shown relative to the shoreline, but depths of fish in water column are schematic.

a 4.5 h set on 29 July were within 61 m of the shoreline, but there were a few out to at least 120 m from shore. It seems likely in this case that, had the net been longer, at least some fish would have been caught more than 122 m offshore. Fishes caught in this set were as follows: 42 least cisco, 30 arctic cisco, 4 arctic char, 1 humpback whitefish and 7 fourhorn sculpin. The waters at Milne Point (East) were also clear (4-6 NTU). In neither of the cases illustrated in Fig. 12 did it appear that the concentration of fish near the shoreline was a response to any sharp gradient in water temperature or salinity.

In all, seven 122-m gill net sets were made off points of land in moderately calm weather:

Site	Date (1978)	Duration (h)	Total No. Fish
Kavearak Point	24 July*	3	32
	8 August	1.5	61
Milne Point	23 August	1	19
	31 August	1	14
	9 September	7	17
Milne Pt. (east)	29 July*	4.5	84
Pingok Island**	23 August	1	13

* Discussed in text and shown in Fig. 12.

**Unnamed SE point in lagoon.

Total numbers of fish caught in these gill nets were 117 least cisco, 52 arctic char, 45 arctic cisco, 18 fourhorn sculpin, 4 broad whitefish, and 4 humpback whitefish. We combined the data from these seven gill net sets and found that distribution patterns were very different between anadromous and marine fish (Fig. 13). The fourhorn sculpin, a marine species, was uniformly distributed but anadromous fish were most abundant near the shoreline. Approximately six times as many anadromous fish were caught in the first (landward) 40 m of net as were caught in the last (seaward) 40 m. Numbers of anadromous fish caught in three distances from shore categories, 0-40 m, 40-80 m, and 80-120 m, were significantly different (Friedman two-way analysis of variance, $\chi_r^2 = 8.64$ $k = 3$, $N = 7$, $P < 0.016$) with numbers of fish at 0-40 m being significantly greater than numbers at 80-120 m ($P < 0.008$). The abundance of

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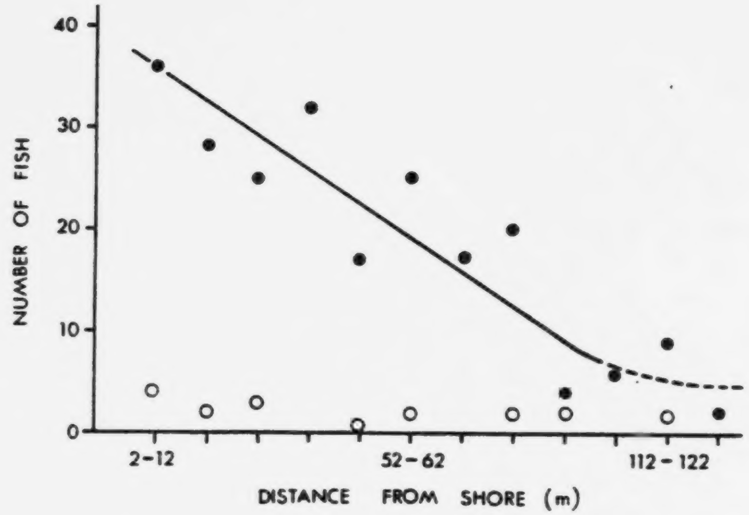

Figure 13. Fish abundance in relation to distance from shore off points of land on seven calm days in 1978. Total numbers of anadromous fish (●) and fourhorn sculpins (○) caught in gill nets are plotted by 10 m interval. No gill net was set between 0-2 m (see 'METHODS').

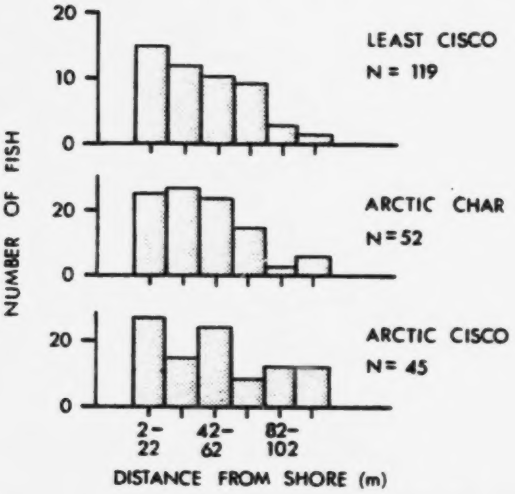

Figure 14. Abundances of three anadromous species of fish in relation to distance from shore off points of land on seven calm days in 1978.

anadromous fish declined steadily with distance from shore out to about 100 m, at which point numbers presumably leveled off. Data from 1977 (Fig. 11) suggested that low densities occurred across the center of the lagoon.

Among the anadromous species, there was a conspicuous absence of habitat partitioning within 122 m of shore (Fig. 14). This probably reflects the migratory nature of these species. Indeed, it has been observed that arctic cisco and arctic char may form mixed schools (Griffiths et al. 1975:99). Fish species that are more sedentary often demonstrate spatial segregation along a shore-to-open-water transect (e.g., Werner et al. 1977).

It would be erroneous, however, to leave the impression that fish are always concentrated along Beaufort Sea shorelines. There are times and places where the shoreline concentration of fish does not occur. We encountered two examples during 1978 (Fig. 15). During a stormy period with rough waters on 9 August, most fish caught were several hundred meters offshore at Milne Point (East). On another occasion (10 August) gill nets set along a transect in the embayment between Milne and Kavearak Points caught no fish near the shoreline, but some fish were taken 1.6 km (1 mi) offshore. In earlier studies, we observed some schools of migrating fish about 300 m offshore at Nunaluk Spit (see first paragraph in this section).

Preliminary netting also indicated that the shoreline distribution of fish was influenced by underwater topographical features such as submerged sand and gravel bars, which characteristically form 100-400 m offshore on the west side of points of land. Although comparative netting was not performed, it appeared that fish were more abundant around these bars than might have been predicted on the basis of distance from shore alone. For example, 122 m gill nets set 0.5 km offshore along the gravel bar off Milne Point caught relatively large numbers of ciscoes and char in a short time: 39 fish in 2 h (3 August 1978) and 21 fish in 1.2 h (5 August 1978).

Our results show that anadromous fish commonly concentrate near shore along the Beaufort Sea coast, but the occurrence and width of

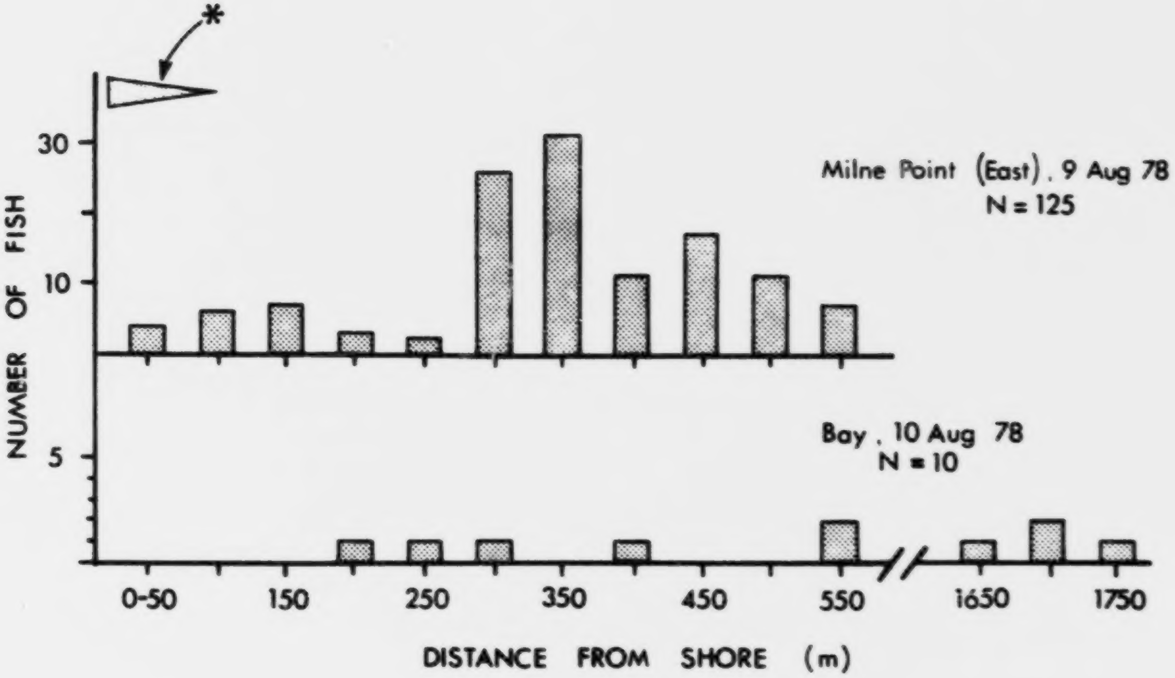

Figure 15. Dispersed distributions of anadromous fish during stormy, rough-water conditions (top) and in a relatively shallow bay between Milne and Kavearak Points (bottom; no nets were set between 550 and 1650 m). The frequent location of the shoreline concentration of fish (see Fig. 13) is indicated by an asterisk.

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this migration corridor are variable, depending on factors such as the configuration of the coast, underwater topography, and weather.

Why fish concentrate along shorelines is not understood, but there are several possibilities:

1. Predator Avoidance - This is an improbable reason since predator densities are low (see 'Predators').
2. Food Abundance - This is not likely since available data indicate that food is more abundant in deeper waters away from the shoreline (Griffiths and Dillinger 1980).
3. Navigation Aid - Perhaps shorelines are useful navigation aids since nearshore waters are often turbid. Lagoon waters are frequently most turbid along shorelines, but perhaps fish can orient along the topographic boundary even in turbid water.
4. Habitat Preference - Fish may prefer the slightly warmer and less saline waters that are generally found along shorelines. This possibility is not entirely satisfactory, however, since waters in the center of the lagoon are slightly warmer and less saline than along Pingok Island shorelines (Figs. 2 and 3), but the catch per unit effort is not correspondingly higher in the lagoon center (Fig. 11). Other relevant habitat factors may include water depth or slope of substrate. (See 'Effects of Physical Factors' for further discussion.)
5. Habitat "Constriction" Points - Perhaps points of land that jut into Simpson Lagoon act as "diversion lines" for fish migrating east or west. A proportion of the fish crossing an embayment would encounter the landmark below its tip and follow its shoreline in order to get around the point. Note, however, that fish are also abundant along fairly straight stretches of the coast (e.g., see location of and catches at Station 1 in 1977, Figs. 1 and 11).

Summer Distribution

Figure 16 depicts general fish distribution during the open-water season. The figure represents a liberal extrapolation of point-sources of systematically-collected data combined with the practical and subjective experience we obtained while sampling for fish in Beaufort Sea coastal waters.

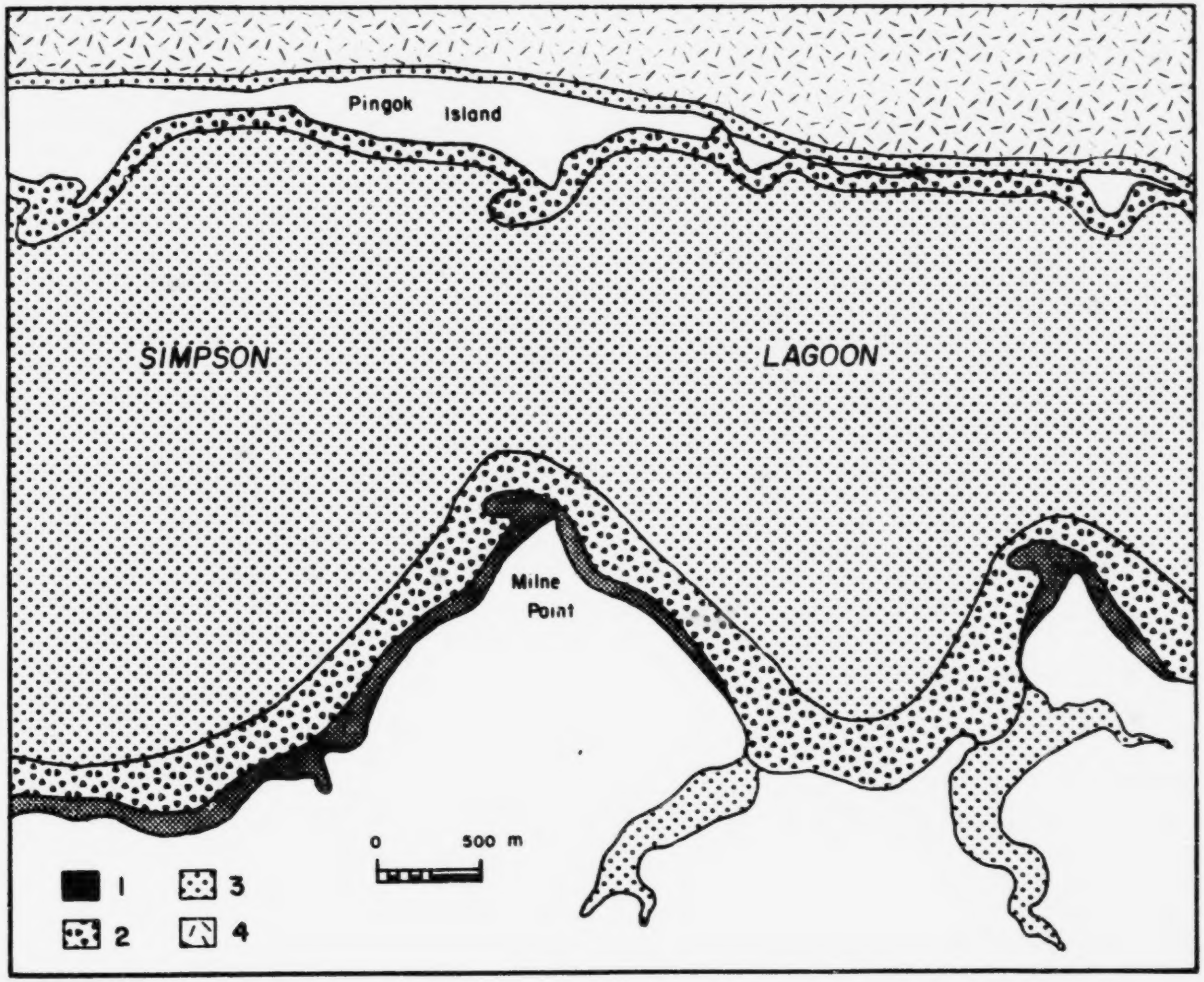
Pingok Island
SIMPSON LAGOON
Milne Point
0 500 m
1
2
3
4

Figure 16. Hypothetical density distribution of nearshore fishes in nearshore portions of the study area. Relative densities range from 1 (high) to 4 (low). Refer to Table 5 for distributions of individual species.

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Four zones of fish density, graded from Zone 1 (highest density) to Zone 4 (lowest density), are proposed:

- Zone 1. Highest densities of fish, occurring in a narrow band about 100 m wide along mainland shorelines, particularly around points of land but not in shallow embayments. Anadromous fishes (arctic and least cisco, char, whitefish) and some marine species (fourhorn sculpin, arctic cod) are abundant in this zone.
- Zone 2. A band of medium density of fish around mainland and barrier island (lagoonside) shorelines, extending perhaps 500 m offshore or to the 1.5 m depth contour. Fish species along the mainland are as in Zone 1, but relatively few anadromous fish other than arctic cisco and char occur in Zone 2 along the barrier islands.
- Zone 3. Generally lower densities of fish in the lagoon center and along a narrow band about 100 m wide on the ocean side of the barrier islands. Principal species caught on outer shoreline of barrier islands are arctic char and fourhorn sculpin.
- Zone 4. Lowest densities of fish (especially low densities of anadromous species) in the cold marine waters seaward of the barrier islands. Marine fishes (e.g., sculpin, cod, snailfish) inhabit these waters. Additional species are encountered farther offshore.

This picture may best describe the distribution of anadromous fish during the open-water season. The depicted density zones are, of course, generalized and could be refined by further studies.

Winter Distribution

Colville Delta. Both anadromous and marine species were found overwintering in the brackish (17.9-31.9 ppt) waters of the lower Colville Delta during the April and May, 1978, sampling period:

Species	Catch Per Unit Effort (No./24-h gill net set) Station A	Station B
arctic cisco	1.9	1.0
least cisco	1.0	0.7
boreal smelt	0	0.5
fourhorn sculpin	0.5	0.2
Bering cisco	0.1	0.1
saffron cod	0	0.02
Gill Net Days	13	44

These catches represent the first records of overwintering areas for anadromous ciscoes in Alaskan Beaufort Sea drainages. The data also indicate that these fishes do not necessarily reside in freshwater habitats during the winter period; however, no ciscoes were found during extensive winter surveys in nearby coastal waters in 1978-1979.

Coastal Areas. The abundance and distribution of the fish species utilizing nearshore habitats in the study area change dramatically during the period of ice cover. This change is marked by the disappearance of all of the dominant anadromous species (cisco, whitefish, and char) that are common during the brief summer. In the November 1978 through May 1979 sampling periods six species of fish were caught. In order of decreasing numbers they were boreal smelt, fourhorn sculpin, arctic cod, saffron cod, snailfish and arctic flounder. With the exception of the anadromous boreal smelt, all of these are marine species. A summary of the winter catch data is presented in Table 10; details of catches by date, location and sampling effort are listed in Table 11.

It appears that boreal smelt and fourhorn sculpin are the dominant fish species in nearshore waters of the study area during winter, and that they are concentrated in Harrison Bay near Thetis Island, which is near the mouth of the Colville River. The boreal smelt is a spring-spawning anadromous species (McPhail and Lindsey 1970), and it is assumed that its apparent concentration in Harrison Bay is a prelude to a spawning migration into the Colville River. This supposition is supported by the observation that the great majority of boreal smelt captured were mature fish in pre-spawning condition. The apparent

Table 10. Summary of winter catch data, 1978-1979. See Fig. 7 for station locations and Table 11 for details of catches by date, location and sampling effort.

Fish	Number of Fish Caught Thetis Island	Simpson Lagoon	Boulder Patch	Narwhal Island	Totals
Boreal smelt	1539	12	0	0	1551
Fourhorn sculpin	1022	0	0	0	1023
Arctic cod	6	21	71	9	107
Saffron cod	36	1	0	0	37
Snailfish	0	0	15	0	15
Arctic flounder	1	0	0	0	1
Totals	2605	34	86	9	2734

Table 11. Summary of 1978-1979 winter catch by date and location. Catch per unit efforts (CPUE) are listed for fish caught by net (gill net, trammel net, fyke net or box trap) per day. Sampling gear is listed in Table 3 and sampling stations in Fig. [illegible].

		CPUE at Stations**				
Date	Fish	Thetis Island	Simpson Lagoon	Boulder Patch	Narwhal Island	Total
13-16 November 1978	boreal smelt	15.2	0.5	0	0	3.6
	fourhorn sculpin	1.2	0	0	0	0.3
	arctic cod	0.5	0.9	0.7	0.5	0.8
	saffron cod	0	0.04	0	0	0.02
	Total CPUE	16.9	1.4	0.7	0.5	5
	Effort (Days)	12	24	18	1	54
11-27 February 1979	boreal smelt	22.2	0	0	0	7.8
	fourhorn sculpin	6.8	0	0	0	2.4
	arctic cod	0	0	3.7	0	0.9
	saffron cod	1.0	0	0	0	0.3
	snailfish	0	0	1.1	0	0.3
	Total CPUE	30.0	0	4.8*	0	11.7
	Effort (Days)	20	7	14	16	57
1 March-1 April 1979	boreal smelt	16.1				
	fourhorn sculpin	13.8				
	saffron cod	0.1				
	arctic flounder	0.02				
	Total CPUE	30.0				
	Effort (Days)	52				
29 April-14 May 1979	boreal smelt	5.8	0	0	0	1.4
	fourhorn sculpin	11.7	0	0	0	2.8
	arctic cod	0	0	0.4	0.5	0.2
	saffron cod	0.9	0	0	0	0.2
	Total CPUE	18.4	0*	0.4*	0.5*	4.6
	Effort (Days)	13	10	17	15	55

* Catches at these times and locations may reflect a change in sampling gear from gill nets to under-ice fyke nets (see Table 3).

**Not listed: (1) Spy island (East): CPUE = 0, effort (days) = 4 (8-2 May 1979)
(2) Spy Island (West): CPUE = 0.2 boreal smelt and 0.3 fourhorn sculpin, effort (days) = 6.1 (8-14 May 1979).

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able to cope with conditions ranging from nearly fresh to salt water, clear to very turbid water, and temperatures ranging from 0 to 14°C (Table 12). Fewer data are available for the winter period, but initial findings for several species suggest a surprisingly wide range of tolerance for salinity--anadromous and marine fish have been caught overwintering in the nearly fresh waters of the Mackenzie Delta (Percy 1975) and the nearly marine waters of the Colville Delta and surrounding nearshore habitats (this study).

Tolerance of a wide range of conditions does not imply that these conditions are equally suitable for fish. For example, one species may prefer low salinities and might move into and out of Simpson Lagoon as salinities change. Such movements, if they occur, might be responsible for the large day-to-day variations in numbers of fish recorded during this study. Therefore, comparisons were made between daily catches (fyke net data) and each of three features of the environment that fluctuated almost daily--salinity, water temperature and turbidity.

Correlation coefficients were calculated for data collected at Milne Point during the summer of 1978. To minimize the effects of seasonal movements of fish and seasonal changes in physical factors, the open-water season was divided into four time periods for analyses: 10-19 July (N = 6 observations during this period), 20 July-10 August (N = 12), 11-31 August (N = 13), 1-20 September (N = 16). General changes in temperature and salinity provided some basis for the selection of these four periods (Fig. 3). Actual ranges of physical variables during these periods were:

Period (1978)	Temperature (°C)	Salinity (‰)	Turbidity (NTU)
10-19 July	5-7	1-18	40-87
20 July-10 Aug	4-13.5	9-28	3-47
11-31 Aug	1.7-7	14-26	4-36
1-20 Sept	0.5-5	13-29	2-98

Since each day's fish catch covered a 24-h period, daily catches of each species were compared to average values for physical data collected at the start and end of each corresponding 24-h period. Correlation

Table 12. Observed temperature, salinity and turbidity conditions where fishes were caught. Summer values include data from Simpson Lagoon (1977 and 1978) and Prudhoe Bay (Bendock 1977); winter data are from various coastal and freshwater locations (Kogl and Schell 1974; Mann 1974; Percy 1975; Bendock 1977; this study).

	Summer Conditions			Winter Conditions	
Species	Temperature °C	Salinity %	Turbidity NTU*	Temperature °C	Salinity %
Arctic cisco	0-13.5	2-32	1-146	-1.7	5-32
Least cisco	1-14	2-32	1-146	-1.7 to 0	0-32
Arctic char	0.5-14	2-32	1-146	0 to 2	0
Broad whitefish	1-14	2-30	2-146	0	0
Humpback whitefish	1-12	2-28	4-146	0	0-28
Arctic cod	0-13.5	3-28	1-146	-2.0	23-31
Fourhorn sculpin	0-13.5	2-31	1-146	-1.7	5-32
Arctic flounder	0-13.5	2-31	1-82	-	5-30
Boreal smelt	1-13.5	1-29	2-140	-2 to -1	1-32

*NTU = 1 represents clear water, > 1 m visibility; NTU = 146 represents very turbid water, about 5 cm visibility.

coefficients were calculated for species when at least 20 fish were caught during a period.

Only 7% of the 72 possible comparisons between daily catches of fish and physical factors were statistically significant:

Species	Statistical Correlation			
	Variable	Period*	Coefficient	P
fourhorn sculpin	temperature	2	-0.588	<0.05
	turbidity	4	-0.507	<0.05
arctic cod	salinity	4	0.655	<0.01
arctic char	temperature	4	0.865	<0.001
	salinity	4	0.693	<0.01

*Periods 2 (20 July-10 August), 4 (1-20 August).

That so few comparisons were significant (almost the number expected by chance alone) suggests that there are no strong or consistent relationships between the numbers of fish caught in the range of temperature, salinity and turbidity values occurring during the four time periods. Even when statistical probabilities obtained for each species and variable during the four time periods were compared by the "weighted Z" test (Rosenthal 1978), the resulting probabilities were generally nonsignificant. A significant relationship was determined in only two cases--positive correlations between salinity and both arctic cod ($P = 0.02$) and arctic char ($P = 0.002$).

These results are not totally unexpected even if the physical variables do affect fish behavior because correlation coefficients are not a particularly sensitive test for this purpose. Several factors could serve to complicate or obscure interpretations and thus result in nonsignificant correlation values. Rough seas, for example, apparently cause fish to move out of shallow water, thereby avoiding capture regardless of temperature and salinity conditions (Fig. 15). Catch data also do not indicate whether fishes spend more time in an area when temperatures/salinities are high or low. Therefore, experimentation on captive fishes is needed to examine possible relationships between fish behavior and changes in physical factors--a topic of current interest since industrial activities (e.g., causeways) in the nearshore environment may alter existing temperature and salinity regimes (Doxey 1977; Bendock 1977).

Fish Movements

General features of the temporal distribution of fish in the study area are that (1) most, but not all, fish use Simpson Lagoon only during the ice-free season, and (2) within this period, the fish are highly mobile and evaluations of their local abundance are complicated by day-to-day pulses of movement and larger scale movements over several-week periods.

During the brief arctic summer, both anadromous and marine fish invade the shallow water zone of the Beaufort Sea. Although nearshore ice may not completely disappear until early July, fish have by this time already been migrating and feeding under the ice and in leads for up to several weeks. The present study and others (Griffiths et al. 1975, 1977; Bendock 1977) show that fish enter nearshore waters almost as soon as there is enough unfrozen water in which to swim.

In Simpson Lagoon the first open-water areas in spring were leads along mainland and island shorelines. When sampling programs began in the lead along the lagoon-side of Pingok Island on 19 June 1977 and along the mainland shore at Milne Point on 27 June 1978, fish were already present and actively feeding. First capture dates for major species are listed below; for most species, arrival dates in the two years were within one week of one another:

Species	Date When First Caught	
	1977	1978
fourhorn sculpin	19 June	28 June
arctic cisco	22 June	27 June
least cisco	30 June	29 June
broad whitefish	*	29 June
humpback whitefish	*	29 June
arctic char	3 July	6 July
arctic cod	12 July	7 July

*No broad or humpback whitefish were caught at Pingok Island in 1977.

Anadromous fish (except boreal smelt) appear to return to freshwater by freeze-up. Marine species, on the other hand, are still present in the lagoon under the ice through November, but diminishing depths of unfrozen water and increasing salinities probably force most, if not all, fish out of Simpson Lagoon and into deeper waters by mid-winter (see 'Winter Distribution'). Because of the thickness of ice in late winter (about 2 m), all fish are excluded from the shallow shoreline habitats that are utilized so extensively during summer months. Some species remaining in the nearshore environment through the winter apparently move to particular areas--virtually all of the boreal smelt, fourhorn sculpin and saffron cod taken were at the Thetis Island station in Harrison Bay off the Colville River.

Seasonal Movements

In the following sections, the movements of major fish species through Simpson Lagoon and adjacent regions are described. Information was derived from three sources: (1) a tagging program to document movements of individual fish, (2) fyke nets which operated daily during the open-water season of 1977 and 1978, and (3) gill nets which were used to sample fish in summer and winter.

The tagging program was conducted to study coastal movements of fish and their residency times in Simpson Lagoon. During the summers of 1977 , 1978, and 1979, 6412 fish were tagged; 3470 large fish (generally >250 mm) were tagged with Floy dart tags and 2942 small fish (generally 100-250 mm) were tagged with metal opercular tags (Table 13). The recovery rate was low. Excluding fish recaptured the day after tagging (since they might have re-entered the fyke net upon release), only 0.6% of the small fish and 4% of the large fish were recovered. Most (84%) of the latter were caught in the Colville Delta commercial fishery. Additional information about movements was obtained by the captures in Simpson Lagoon of 43 fish that had originally been tagged outside the study area by the Alaska Department of Fish and Game (ADF&G). Mortality due to tagging appeared to be minimal (see 'METHODS'). All recapture data are listed in Appendix 1. The recapture of 196 fish

Table 13. Summary of fishes tagged in Simpson Lagoon and recaptured at various locations, 1977-1979.

	Fish Tagged						Recaptured
	1977		1978		1979		
Species	Floy Dart Tag	Opercular Tag	Floy Dart Tag	Opercular Tag	Floy Dart Tag	Total	Total
Fourhorn Sculpin	0	2381	0	4	0	2385	17
Least cisco	126	46	893	5	873	1943	109 (28)*
Arctic cisco	30	57	369	5	371	832	45 (1)
Arctic char	55	281	349	0	1	686	14 (10)
Broad whitefish	4	1	166	5	17	193	4 (1)
Humpback whitefish	1	0	64	0	62	127	4 (3)
Arctic cod	0	110	0	0	0	110	1
Pink salmon	0	0	88	0	0	88	1
Arctic flounder	0	47	0	0	0	47	1
Grayling	0	0	1	0	0	1	0
Totals	216	2923	1930	19	1324	6412	196

*Number in parentheses indicate fish tagged by ADF&G and recaptured in Simpson Lagoon.

during this study allows us to speculate about the movements of fish in coastal waters. However, any patterns inferred from these data should be viewed in the context of several factors:

1. Recapture Location. Locations of recaptures will be predictably clumped at the few coastal sites where fishing programs operate. Such operations occurred in Prudhoe Bay during summers of 1976 and 1977 Bendock 1977; Doxey 1977), Simpson Lagoon during summers of 1977, 1978 and 1979 (this study), and the Colville Delta in early winter every year (Helmericks' commercial fishery). About 65,000 cisco and whitefish are harvested annually in the Colville commercial fishery which partially accounts for the large numbers of recaptures at this site.
2. Small Fish. Recaptures of small fish (marked with opercular tags) are not to be expected outside our study area because these fish are not sought by fishermen and small fish are generally not susceptible to capture by gill net or angling.
3. Direction of Movement. The net direction of movement between release and recapture sites depends on when as well as where fish were tagged. Anadromous fish tend to move away from rivers of origin in early summer and return to those rivers in late summer.
4. Historical Perspective. Arctic char in the Sagavanirktok River were the object of an extended tagging program from 1970 to 1974. The probability of catching a tagged char from this drainage is greater than for other North Slope rivers.

Movements of the major fishes in Simpson Lagoon are described below.

Arctic Cisco. The arctic cisco was the first species caught in the study area each spring. During the early breakup period these fish were abundant in open-water leads around Pingok Island (Fig. 17). Individuals caught at this time were primarily mature spawners, which may have overwintered in the nearby Colville Delta (see 'Winter Distribution'). It appears that spawners of the year leave their overwintering areas at the first opportunity, feed voraciously in Simpson Lagoon for about two weeks (all had stomachs full of amphipods and mysids), and then leave coastal waters.

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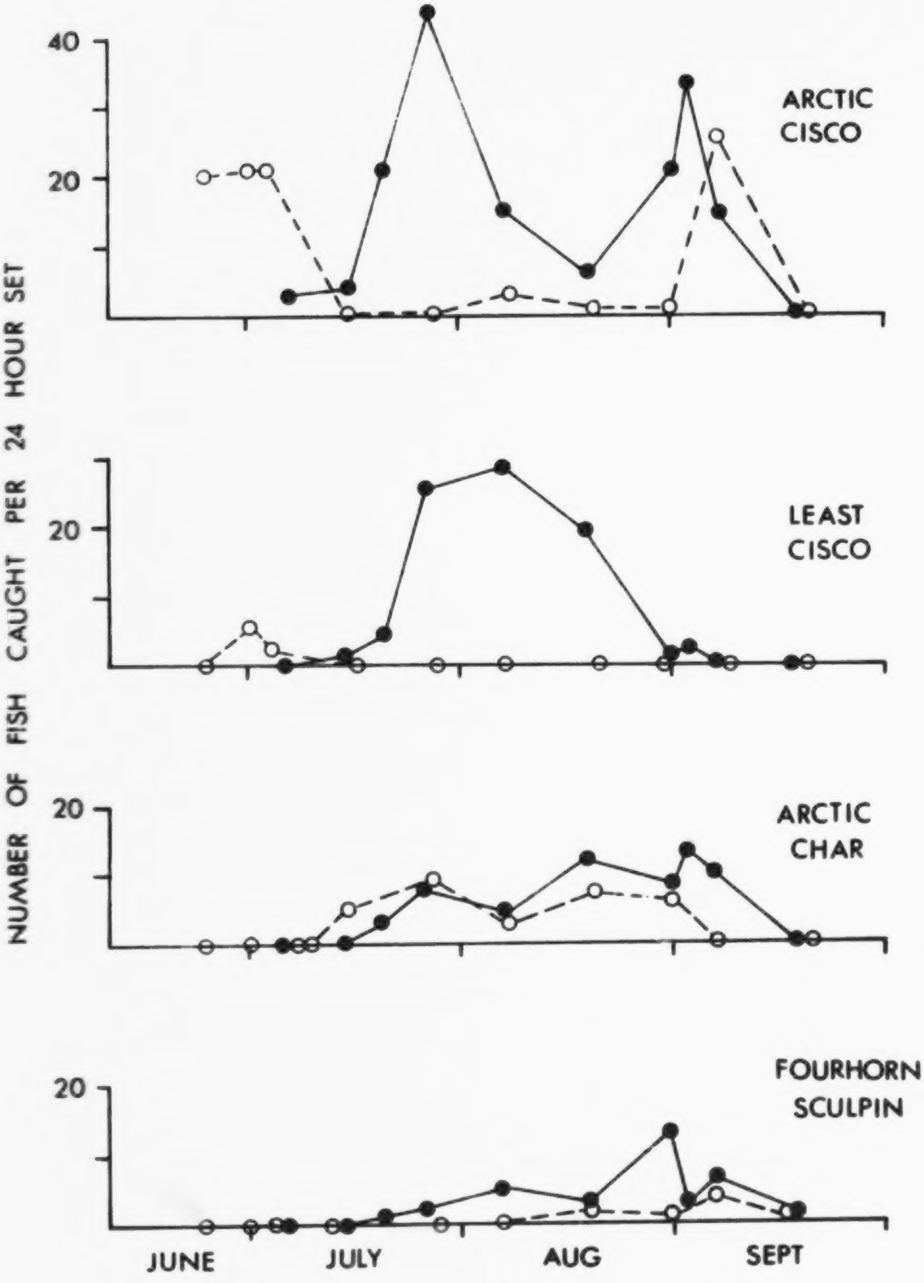

Figure 17. Seasonal abundance of fish caught by gill net along mainland (solid dots) and Pingok Island (open dots) shoreline, 1977.

Unlike the mature fish that would spawn in fall, juvenile and mature non-spawning arctic cisco were abundant in nearshore environments throughout the open-water season. Figure 17 shows two major periods of activity, which probably represent migrations from the Colville River in the latter half of July and back to the Colville in early September. This bimodal activity pattern was not observed for arctic cisco at two locations more distant from the Colville:Kaktovik Lagoon (Griffiths et al. 1977) or Prudhoe Bay (Bendock 1977).

Daily fyke net catches of arctic cisco (Fig. 18) indicate two points: (1) daily catches varied greatly, suggesting that fish were passing by in pulses or schools rather than in a large, even migration, and (2) temporal patterns varied substantially between years. Most arctic cisco intercepted by the 1977 fyke net were small fish (92% of those caught were <200 mm long); peak movements of these small fish occurred in late August and early September of 1977, perhaps indicating their return to the Colville River. The following year, these small fish were proportionally much less abundant in the fyke net (55% of total arctic cisco catch) and the autumn peaks of activity were absent. Most arctic cisco traveled eastward (away from the Colville) in early July 1978 and westward in mid-August 1978, as expected if the Colville River is the source of arctic cisco in the study area. It is not known why these fish apparently returned toward the Colville much sooner (or much later) in 1978 than 1977.

Few arctic cisco were caught by gill or fyke nets in mid-September (Fig. 17 and 18), and none were caught in the November or February winter sampling program. Thus arctic cisco had returned to the Colville Delta region or other locations by the end of September or October.

Of 38 arctic cisco tagged in Simpson Lagoon during summer and recaptured the same year, 37 were recaptured under the ice in the lower Colville Delta during the October-December period (Fig. 19). One was recaptured at Milne Point, the site of tagging, 29 days after release.

Approximately 16% (n = 7) of the total arctic cisco recaptures were made 1-2 years after tagging. The most interesting of these was a fish tagged on 18 August 1978 in Simpson Lagoon and recaptured 270 km

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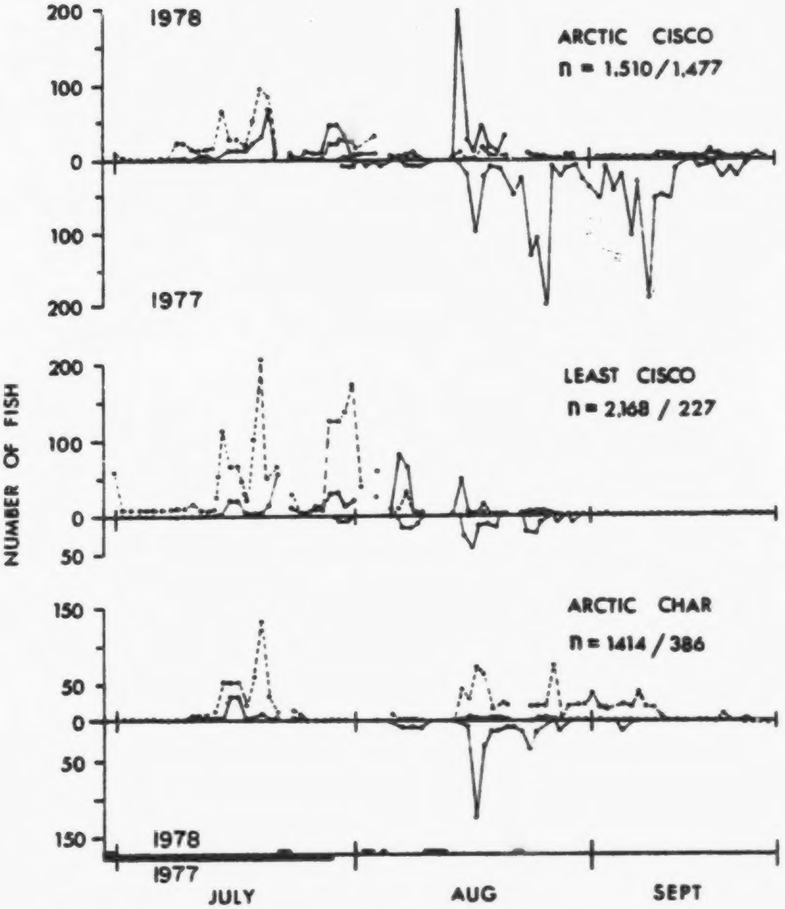

Figure 18. Comparison of daily fyke net catches along the mainland shoreline in 1977 and 1978. Nets were located at Milne Point in 1978 (upper graphs) and 6 km west of Milne Point in 1977 (lower graphs). Numbers of fish caught are indicated by year: 1978/1977. For 1978 catches, solid lines show fish moving westward; dashed lines show eastward movement. Dark bars along abscissa indicate periods when fyke nets were not in operation in 1977 and 1978.

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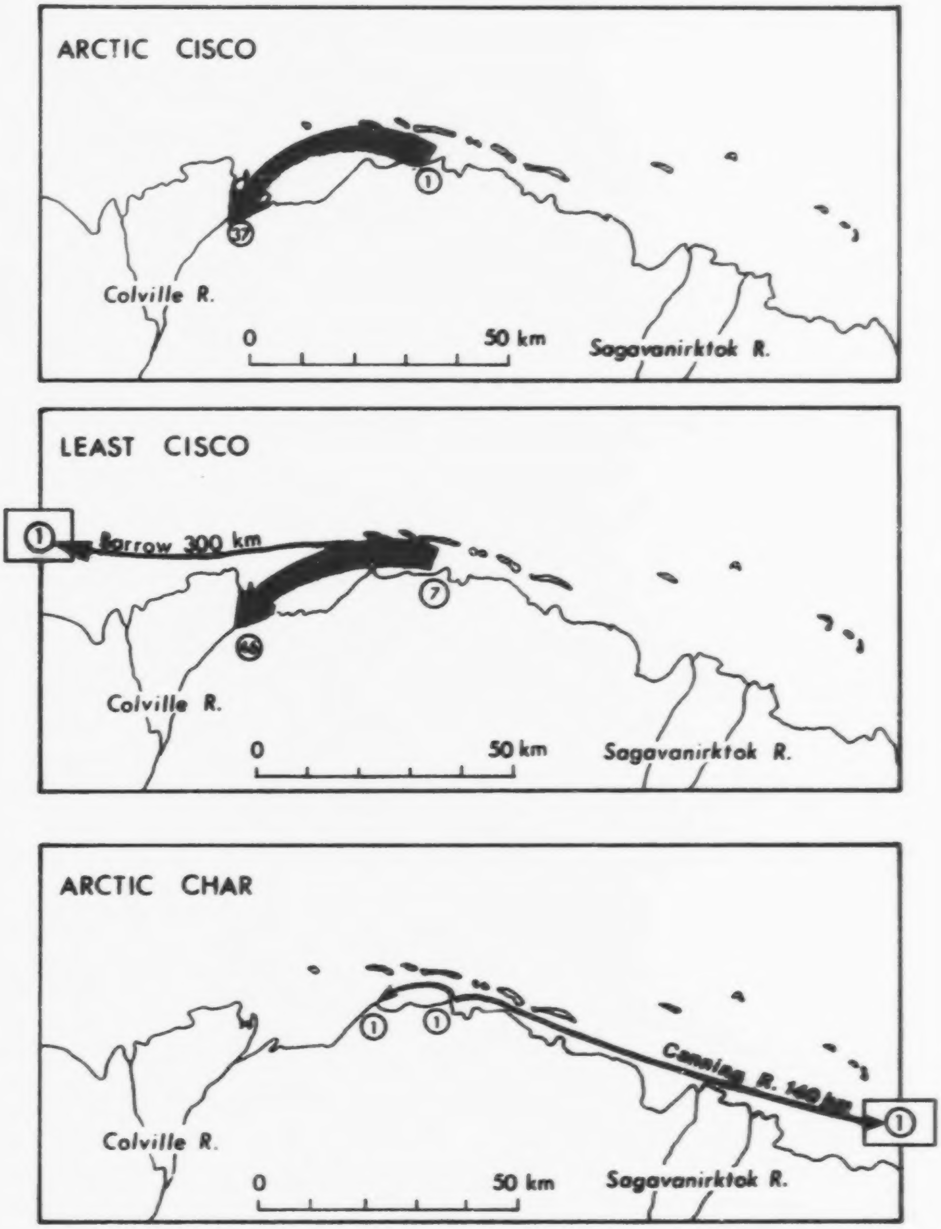
ARCTIC CISCO
①
㊲
Colville R.
0
50 km
Sagavanirktok R.
LEAST CISCO
①
Barrow 300 km
⑦
Colville R.
0
50 km
Sagavanirktok R.
ARCTIC CHAR
①
①
Canning R. 140 km
①
Colville R.
0
50 km
Sagavanirktok R.

Figure 19. Coastal movements of fish tagged in Simpson Lagoon and recaptured during the year of tagging. Numbers of recaptures at each site are indicated.

eastward on 31 July 1979 at Griffin Point in a subsistence fishery. Five other arctic ciscoes were recaptured in the Colville Delta in late fall; another caught in Simpson Lagoon had previously been tagged in Prudhoe Bay by ADF&G.

Least Cisco. In contrast to the arctic cisco described above, almost all least cisco in the system were large fish; 89% and 98% of all least cisco caught in fyke nets in 1977 and 1978, respectively, were >200 mm in length. This species was rare along barrier islands but was abundant along the mainland in mid-summer (Fig. 17). Fyke net catches in 1978 showed that the predominant direction of movement was away from the Colville (east) in July; fewer fish moved towards the Colville (west) in August (Fig. 18).

The postulated coastal pattern of movements for this species is as follows. In spring, least cisco enter coastal waters from their overwintering sites in the Colville Delta and other unidentified locations farther west. Those fish dispersing eastward move through Simpson Lagoon in early and mid-summer. Thereafter, there is a build-up of these fish in Prudhoe Bay, with peak numbers occurring there in late August and September (Bendock 1977). Apparently least cisco do not travel much farther eastward, since few have been caught between the Canning River and the Canadian border (Roguski and Komarek 1972; Ward and Craig 1974; Griffiths et al. 1977). Since some of these fish were recaptured in the Colville Delta in October and November (described below for fish tagged in Simpson Lagoon; see Bendock (1977) for data from fish tagged in Prudhoe Bay), it appears that a large westward movement of least cisco must occur in late autumn. Few westward-moving least ciscoes were caught in Simpson Lagoon by the time sampling ended in late September (Fig. 18), so the main westward movement apparently occurs in October. No least cisco were subsequently caught in nearshore waters during the November, February or March-May winter sampling efforts.

Recapture data are consistent with the view that the Colville River is a principal source of least cisco in coastal waters east of this river (cf. Craig and McCart 1976; Bendock 1977; Doxey 1977). Most recaptures (87% of those recovered the same year that they were tagged) were taken in the Colville Delta commercial fishery (Fig. 19). These fish were tagged in Simpson Lagoon in the summer and recaptured under the ice of the Colville Delta during October-December in commercial and subsistence fisheries. One other tagged fish was recaptured at a fishing camp near Barrow (specific location unknown) in the fall. Perhaps this least cisco originated in a stream to the west of the Colville.

Almost half of the 109 least cisco recaptures were made 1-3 years after being tagged. Three of these were recaptured in Simpson Lagoon and 24 in the Colville Delta in subsistence or commercial fisheries. Twenty-eight recaptures in Simpson Lagoon had been previously tagged in Prudhoe Bay by ADF&G.

Based on tagging results, Bendock (1977) suggested that least cisco exhibit strong schooling behavior because he noted that fish tagged at the same time and place were occasionally recaptured together a long time afterwards at another site. Our own data support the observation that some ciscoes stay together. The criteria we used were that fish had to be tagged at or very near the same site within one day of each other, and similar restrictions for their recapture applied. This occurred on 14 occasions involving two or three fish each time (Appendix 1). Six occasions involved only least cisco, one involved only arctic cisco and five were with mixtures of both least and arctic cisco. In most cases, these fish had been tagged in Simpson Lagoon in summer and recaptured 2-4 months later in the Colville Delta fishery:

Fish Group*	Months Elapsed between Tagging and Recapture
1. least cisco only	0.07, 2.5, 3.5, 3.7, 4, 14.7, 15.8, 23.9
2. arctic cisco only	3.6
3. least and arctic cisco	2.5, 3, 3.1, 3.4, 4.1

*There were two or three fish in each group.

On three occasions, the fish were recaptured together 1-2 years later.

Arctic Char. Char moving through the lagoon were generally large fish; 95% and 75% of all char caught in 1977 and 1978, respectively, were >200 mm in length. Their widespread distribution in the lagoon and around the barrier islands (Tables 5 and 8) suggest that they are more tolerant of marine waters than are most other anadromous species. Similar patterns of seasonal abundance were evident along mainland and Pingok shorelines (Fig. 17). Char were common in nearshore waters for most of the open-water period, and fyke net catches showed that they remained in the lagoon about 2 weeks longer in 1978 than in 1977 (Fig. 18).

The direction of movement of char, as indicated by the 1978 fyke net data, was predominantly from west to east. However, in this case the location of the fyke net may have biased catch statistics. It is possible that the submerged gravel bar off Milne Point induced some westbound char to bypass the fyke net (see 'METHODS'). Char caught in gill nets did not exhibit the preponderance of eastward movement evident in fyke net catches. In 11 gill net sets along the mainland shore during the 15 July-9 September 1978 period, 51% of 163 char caught entered the net from the east side, and 49% entered from the west. It is therefore concluded that the fyke net data do not accurately reflect the directions of movement of arctic char. (Other species do not lend themselves to a similar analysis because of apparent reversals in movement and the timing of gill net sets in relation to the timing of peak movements of fish.)

Recaptures of marked arctic char, though few in number, indicate that a large proportion of the individuals using Simpson Lagoon originate from the nearby Sagavanirktok River. Seven char that were recaptured in the lagoon had been tagged 4-7 years earlier in the Sagavanirktok drainage and one tagged in the lagoon was recaptured in the Sagavanirktok drainage. Two additional fish caught in Simpson Lagoon had been tagged 1-2 years earlier in Prudhoe Bay.

Only three char were tagged at Milne Point and recovered the same year. One was caught at Milne Point 25 days later, the second at Oliktok Point, and the third in the Canning River approximately 140 km to the east (Fig. 19).

Arctic Cod. This species provided the most dramatic example of annual variability recorded during this study (Fig. 20). Based on our 1977 findings in Simpson Lagoon and Bendock's (1977) observations the previous year in Prudhoe Bay, a modest increase in cod numbers was expected as freeze-up approached, but we did not anticipate the massive school of cod that swept through the lagoon in mid-August of 1978. During a nine-day period (14-22 August), an estimated 124,200 arctic cod were caught in the Milne Point fyke net. The fish were highly mobile as indicated by erratic daily catches; for example, approximate daily catches during the period 18 to 22 August were 17,000, 42,000, 6,000, 40,000 and 15. There was no clear directional pattern of movements at this time (Fig. 20). These were generally small and young fish (60-160 mm, which correspond to ages 1-3; see 'Additional Life History Data for Fishes').

The cod run was not restricted to Simpson Lagoon, but was also observed elsewhere along the Beaufort Sea coastline. Very large numbers of this species were reported in August 1978 in Prudhoe Bay on the west side of the ARCO causeway (C. Broad, pers. comm.); he observed a single school of cod approximately 35 m wide and 300 m long traveling in the shallow water adjacent to the causeway. Fish densities in this school were high, as indicated by the capture of 12 cod in a small plankton net (0.13 m^2 opening) pulled vertically through 0.5 m of water. A very rough estimate of the number of cod in this school is 1-2 million fish. This estimate is based on the above dimensions and corresponding assumptions of 12 cod/0.13 m^2 surface area of water or 12 cod/(0.13 m^2 x 0.5 m) volume of water and an average water depth of 1.2 m. The tendency of arctic cod to travel in large schools has been observed in other arctic areas (Bain and Sekerak 1978).

Arctic cod continued to occur throughout the nearshore area in November 1978, and were found at the "Boulder Patch" and Narwhal Island sites in February and May 1979 (Tables 10 and 11).

Fourhorn Sculpin. Large fourhorn sculpins, generally 140 to 240 mm long, were present in low numbers through most of the summer (Fig. 17). Although gill net and beach seine data show that these large sculpins

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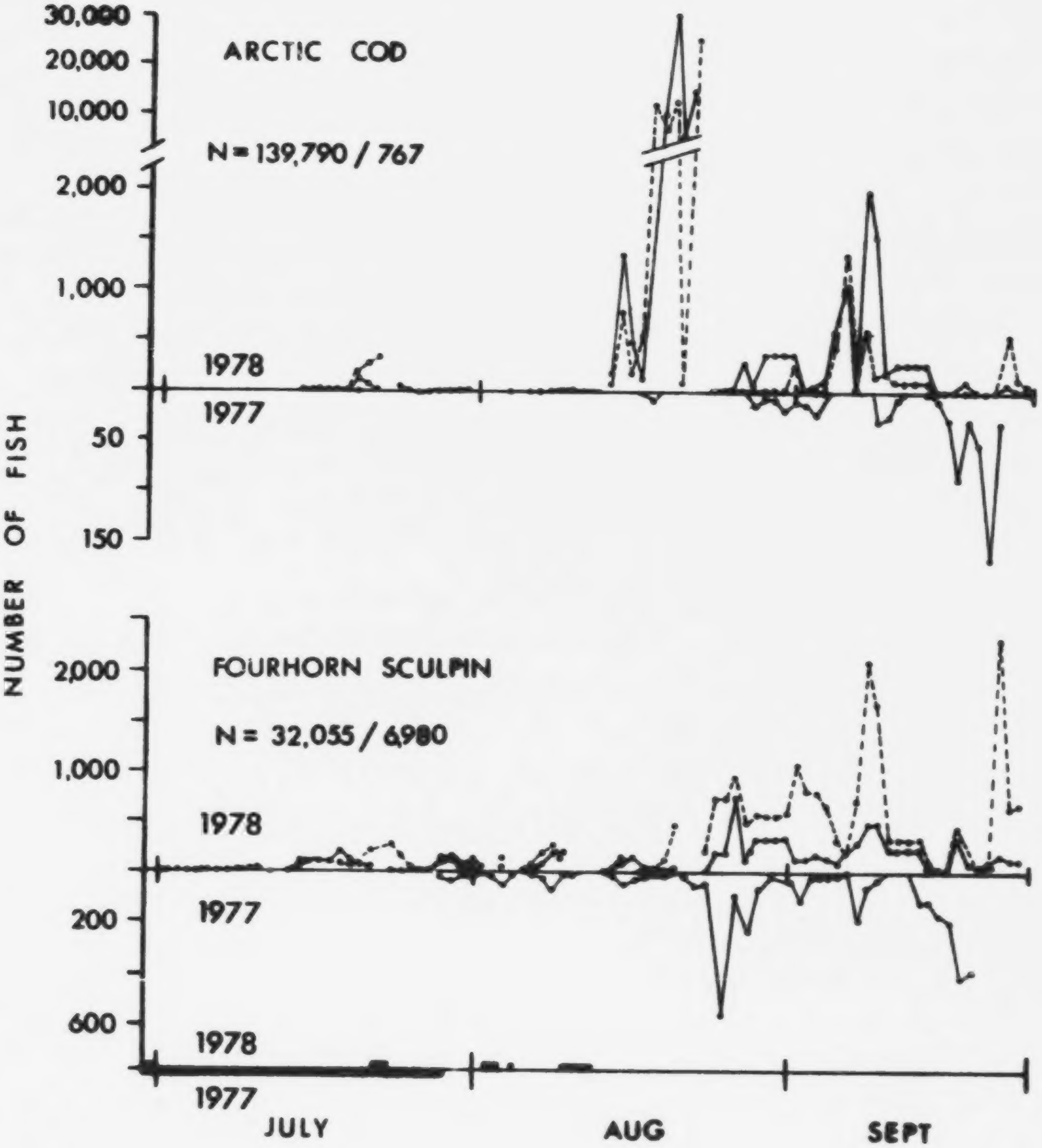

Figure 20. Comparisons of daily fyke net catches along the mainland shoreline in 1977 and 1978. See Fig. 18 for explanation of symbols.

were more abundant along the mainland shoreline than near the barrier islands (Tables 5 and 8), these differences were not statistically significant; fyke nets caught almost equal numbers of small sculpins at both locations (Table 9). Numbers of this species increased in both years as the open-water season progressed (Fig. 20), but winter data indicate that these fish leave the lagoon again in winter (Table 11). It appears that they then move to deeper waters such as those around Thetis Island (Fig. 21). The presence of spawned-out sculpins at the Thetis Island site in February suggests that they may spawn in that area. The 17 recaptures of marked fourhorn sculpins are described in the next section ('Residency Time in Simpson Lagoon'; see also Table 14).

Boreal Smelt. In summer, these fish were relatively sparse (0-0.7% of catches, Table 4) and they occurred sporadically in Simpson Lagoon from 11 July-18 September. Winter data indicated that they move into nearshore areas when these areas are covered by ice. A concentration of boreal smelt was found at the Thetis Island site from November through May 1979 (Fig. 21); these smelt were presumably gathering for a spring spawning run into the Colville River. The abrupt disappearance of boreal smelt from the Thetis Island station on 9 May coincides with the arrival of melt water from the Colville River and suggests that the spring breakup triggers a spawning run of these fish into the Colville drainage.

Broad and Humpback Whitefish. Populations of broad and humpback whitefish enter coastal waters from the Colville and Sagavanirktok rivers (Bendock 1977), but little is known about their movements. One broad whitefish tagged at the Milne Point on 1 July 1978 was recaptured there after 37 days, and one traveled from Milne Point to Oliktok Point in early September. Another broad whitefish tagged at Milne Point on 10 July 1978 was taken in the Nuiqsut subsistence fishery in the lower Colville Delta in October of the same year.

One broad whitefish and four humpback whitefish were tagged in Prudhoe Bay or Simpson Lagoon and recaptured 1-2 summers later in Simpson Lagoon.

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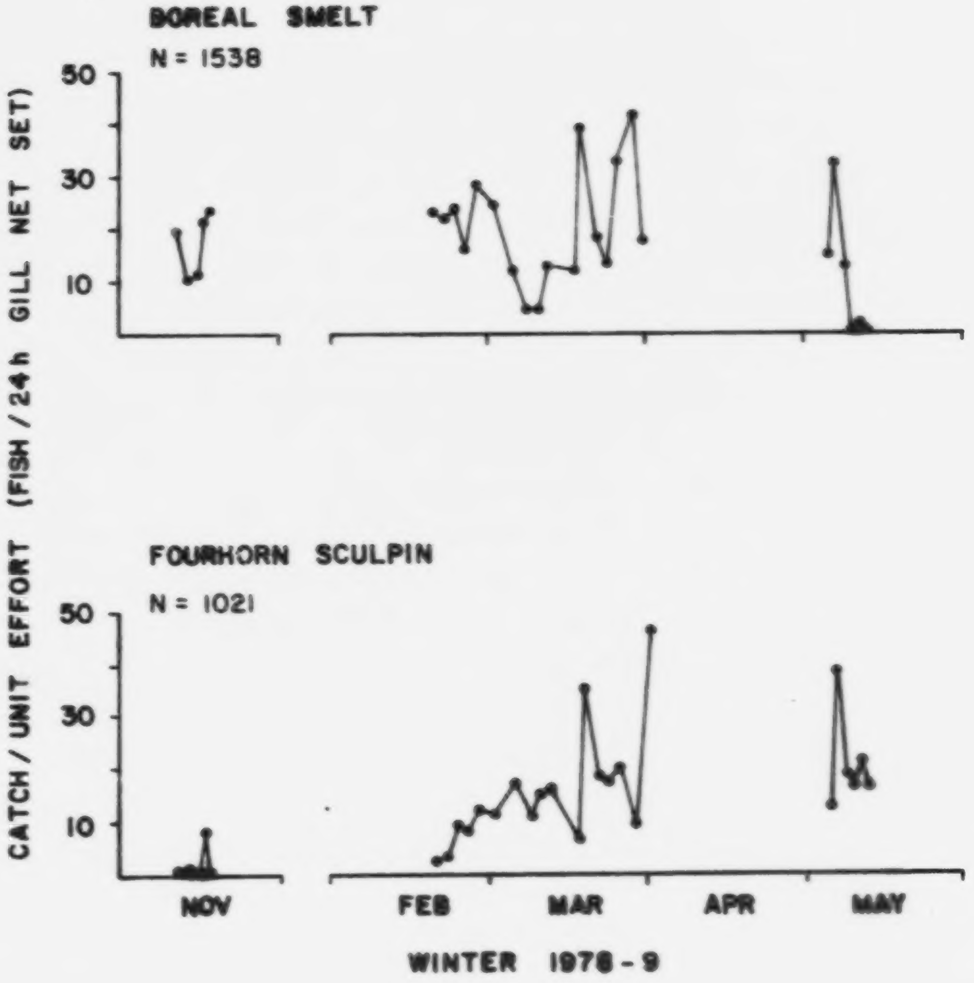

Figure 21. Under-ice catches of boreal smelt and fourhorn sculpin at the Thetis Island station off the Colville River. Gill nets operated continuously during the three periods shown; data points are the average catch per unit effort for 2-5 day intervals.

Pink Salmon. A small run of pink salmon passed through Simpson Lagoon in 1978. The run occurred during 4-9 August 1978 when 87% of the total summer's catch of pinks (n = 166) were caught at Milne Point. Most fish (84%) were traveling in an eastward direction. One fish tagged in the lagoon on 6 August was recovered the next month in a subsistence net at Barrier Island, about 250 km to the east.

Residency Time in Simpson Lagoon

Although it is difficult to determine the time that fish spend in an area, there are two basic reasons why this information is desirable:

1. An implicit assumption in this project has been that estuarine environments, such as Simpson Lagoon, are biologically special habitats in the arctic, just as they are in temperate latitudes. Does Simpson Lagoon provide essential habitat for some fishes? Do fish spend more time in lagoon habitats than in non-lagoon segments of the Beaufort Sea coastline?
2. If oil or a toxic chemical accidently spilled into a lagoon, would only those fish already present be affected, or would new fish continually move into the area from surrounding waters?

It was not feasible to obtain precise information about residency time, but we obtained some useful information by examining (1) patterns of tag recaptures, and (2) average rates of longshore movement of tagged fish.

Pattern of Recaptures. Numbers of fish that were both tagged and recaptured in Simpson Lagoon were low, but these data provide some indication of residency time of the fish.

For large anadromous fish (mainly arctic cisco, least cisco, and arctic char), the paucity of recaptures suggests that these fish do not linger in the lagoon. Despite a continued program of fyke and gill netting in 1977 and 1978, and a 12-day fyke net program in 1979, only 15 of the 3470 large fish marked in the lagoon were recaptured in the lagoon during this study. Of these, 12 were recaptured the same year they were tagged and 3 were recaptured one year later. Excluding the latter group, the days elapsed between tagging and recapture were:

Species	Days Elapsed between Tagging and Recapture
least cisco	2, 2, 2, 4, 4, 5, 6, 28
arctic cisco	29
arctic char	24
broad whitefish	2, 38

Seven of these fish were recaptured at the same site after 2-6 days and one was recaptured 3.2 km away after 5 days; the remaining four individuals, all recaptured about one month after tagging, may well have migrated out of Simpson Lagoon and back again.

The significant point is that these 15 fish represent only 0.4% of all tagged large fish. Thus, a large portion of these fish either moved quickly out of the sampling area or avoided recapture.

Tag recaptures of small fish also provide some information on the movements of these fish and their residency times in Simpson Lagoon. In 1977, 2923 small fish were tagged and 15 were recaptured: 13 fourhorn sculpins, one arctic flounder, and one arctic cod. The arctic flounder was recaptured 21 days later at the same site (Milne Point); the arctic cod two days later at the same site (also Milne Point). The following numbers of days elapsed between tagging and recapture of the 13 fourhorn sculpins: 2 days (n = 5 fish), 3 (1), 5(3), 16(1), 19(1), 21(1), 24(1). Eleven of these fourhorn sculpins were recaptured at the site where they were originally tagged (Table 14); the other two crossed the lagoon from the mainland and were recaptured 19 and 21 days later at Pingok Island. Four of the 2381 fourhorn sculpins tagged in 1977 were recaptured in shallow water in 1978; three of these were recaptured about 5 km from their tagging site.

Tagging data for the fourhorn sculpin, coupled with what is known about the species, suggest that these marine fish may reside in a particular region for one or more summers. Andriyashev (1954) comments that this species "lives permanently near the coast without accomplishing any considerable migrations". In addition, males of this species are known to establish territories during their reproductive period in fall and winter (Westin 1969). Sculpins apparently leave Simpson Lagoon in winter, and certainly must abandon the shallow, nearshore area of the

Table 14. Tagging and recapture distribution of fourhorn sculpins in Simpson Lagoon, 1977-1979.

	Tagged		
	1977		1978
Recaptured	Mainland (n=1217)	Pingok Island (n=1164)	Mainland (n=4)
1977			
Mainland	7	0	-
Pingok Island	2	4	-
1978			
Mainland	3	1	0
1979*			
Mainland	0	0	0
Pingok Island	0	0	0

*Mid-summer sampling effort (see METHODS); n = 4736 fourhorn sculpin caught.

lagoon in winter. The recapture of four individuals in shallow portions of the lagoon one summer after marking suggests that at least some individuals return to that area after having spent the winter elsewhere.

Net Rate of Movement. As fish travel along the coastline, their net rate of movement is a complex function of the frequency, duration and nature of feeding, resting, turning, migrating, etc. Recapture data can provide information about the net rate of movement. From this net rate, we can estimate the time that an average fish might spend while traveling the length of Simpson Lagoon.

An estimate of net movement rates was obtained by using all available mark and recapture data for anadromous fish in Beaufort Sea waters. Only the fish both marked and recaptured along the coast in a single year were useful for these purposes. Sources of these data are the present study and another conducted by the Alaska Department of Fish and Game (Bendock 1977; Doxey 1977). ADF&G maintained several fyke nets in Prudhoe Bay and tagged nearly 5000 anadromous fish in 1976 and 1977. Suitable tag data (i.e., complete details of tagging and recapture dates and locations, or reasonably complete data from which time and distances could be inferred) were available for 78 fish in the ADF&G studies and 8 fish from Simpson Lagoon. These fish had traveled net coastal distances of 0-241 km in 1-21 days (typically 0-20 km in 1-10 days). In all cases, a correction factor of 0.25 days was subtracted from the elapsed time between release and recapture to allow for the average time that recaptured fish spent in the ADF&G fyke net (fyke nets were checked twice daily, weather permitting). A 0.5 day correction was used for our own data since fyke nets were checked once a day. Data on fish that migrated from coastal waters to spawning sites in North Slope rivers were not included in these calcuations.

The average net rate of travel was similar for least cisco, arctic cisco and combined species (49 least cisco, 30 char, 3 humpback whitefish, 2 broad whitefish and 2 arctic cisco):

Fish	Net Rate (km/day) Mean	range	SD	n
least cisco	2.9	0-12	3.1	49
arctic char	2.8	0.1-23	5.4	30
combined species	3.1	0-23	4.2	86

These rates may be biased downward since the nature of the tagging programs made it more likely to catch a fish that remained near the tagging station than one which swam away. However, the rate for combined species only doubles if we analyze only fish recaptured at least 4 km away from their tagging site ($\bar{x}$ = 5.6 km/day, SD = 4.6, n = 45).

At these rates of longshore movement (2.9-5.6 km/day), the mean residency time for an anadromous fish in Simpson Lagoon (37 km shoreline length) would be 7-12 days, assuming that the fish maintained the same net direction of travel throughout its period of residency in the lagoon. For those fish that characteristically travel eastward in early summer and return in late summer, total residency time for the summer would be 14-24 days.

At a rate of 2.9-5.6 km/day, an anadromous fish that entered coastal waters for 2 months would be able to travel about 90-170 km from its stream of origin before having to turn around. It is not known how realistic this range estimate is, but various tagging studies in the Beaufort Sea area each provide a few recaptures of anadromous fish that traveled twice this distance in coastal waters during a single summer (Glova and McCart 1974; Furniss 1975; Bendock 1977; Doxey 1977; this study).

Migrating cisco and char are capable of much faster swimming speeds than the net movement rates calculated above. Speeds of 0.9 m/s or 78 km/day have been recorded in coastal waters when fish apparently were returning to fresh water in the fall (re-calculated from data of Griffiths et al. 1975). If fish entered coastal waters and proceeded outward at the slower rate (2.9-5.6 km/day), but then returned to their North Slope rivers at a rapid rate (50-75 km/day), their coastal range would be extended to 200-300 km.

It is interesting to note that these rough calculations would account for the observed scarcity of least cisco in the Barter Island region of the Beaufort Sea coast (Craig and McCart 1976; Griffiths et al. 1977). Barter Island is about 250-300 km from each of the two rivers (the Colville and Mackenzie rivers) that support major stocks of this species. Perhaps this distance is too great for most least cisco to travel in the time available. These two rivers are also major sources of arctic cisco; however, there is no similar hiatus in their distribution in the area mid-way between these rivers.

Population Numbers

Population Estimates of "Catchable" Arctic and Least Cisco

In this section, we derive estimates of numbers of "catchable" fish for two of the most important anadromous fishes in the study area, arctic and least cisco. "Catchable" fish are defined as those ciscoes large enough to be caught in the commercial fishery in the Colville Delta. These include primarily large immature recruits and mature non-spawners, both of which frequent coastal waters in summer and return to overwinter in areas like the Colville Delta. Details of the age structure and maturity of fish taken in coastal waters and the Colville commercial fishery are presented in 'Additional Life-history Data for Fishes'.

The tagging program conducted in Simpson Lagoon provides a preliminary basis for estimates of the "catchable" segment of these species. The operation of a commercial gill net fishery for arctic and least cisco in the Colville Delta during October through December provides recaptures of fish that were originally caught by fyke net and beach seine in Simpson Lagoon. These circumstances provide an opportunity to estimate numbers of catchable fish using the Petersen single-census procedure for estimating the population size (Ricker 1975). However, we must emphasize that the assumptions upon which the Petersen estimate is based are not necessarily fulfilled and so the resulting population estimates are only rough approximations. These assumptions are that tagged and untagged fish mortalities are equal, that tagged and untagged fish are equally vulnerable to capture, that there is random mixing of marked and unmarked fish, and that there is a negligible amount of recruitment. However, one of the most important uncertainties of the experiment relates to the assumption that tagged and untagged fish are equally vulnerable to capture--the fish were tagged in coastal lagoons and the main point of capture was in the Colville River, so we must assume the following:

> The Colville River is presumed to be the major source of cisco stocks which enter the Simpson Lagoon study area.

Although based on limited information, the latter assumption is not unreasonable. The Colville River, Alaska's largest North Slope drainage, lies immediately adjacent to the study area. It contains large populations of arctic and least cisco, large enough to support the North Slope's only commercial fishery (described in 'Influence of Other Organisms'). It is also known that some ciscoes in Simpson Lagoon originate and/or overwinter in the Colville, since most of our tag recaptures were from the Colville fishery (although this is partly to be expected, since recapture efforts were greatest at this site--see 'Fish Movements'). Bendock (1977) reached a similar conclusion about least cisco in Prudhoe Bay--"tag returns and movement patterns obtained during 1976 indicate that the majority of least cisco captured along the coast move out of, and return to, the Colville River". The only other North Slope rivers known or suspected to support ciscoes are a few rivers near Barrow and the Mackenzie River in Canada. This information is reviewed in more detail in 'Freshwater Sources of Arctic Cisco' and 'Freshwater Sources of Least Cisco' (in 'Additional Life-history Data for Fishes').

Numbers of marked, recaptured and commercially caught fish are listed for 1976 to 1979 in Table 15. The 1976 data were obtained from a tagging program conducted by the Alaska Department of Fish and Game (Bendock 1977). In this case, the fish were tagged in Prudhoe Bay during the 1976 open-water season and were recaptured in the commercial fishery the same year. These data require the same assumptions and involve the same restrictions as do the Simpson Lagoon estimates.

Table 15. Estimates of the "catchable" populations of arctic and least cisco in the Colville River seagoing population, 1976-1979.

	Arctic Cisco				Least Cisco			
	1976*	1977	1978	1979	1976*	1977	1978	1979
Total tagged	628	30	369	371	3,185	126	893	873
Correction for size	22%**	26%	18.8%	77.6%	25.3%***	25.3%***	26.1%	24.5%
Effective number tagged	490	22	300	83	2,379	94	660	659
No. in commercial catch[††]	31,659	31,796	18,115	7830[†]	34,620	14,961	21,681	24,175[†]
No. recaptured	19	4	26	5	269	3	32	8
Population estimate (unbiased)	777,253	146,266	201,960	109,634	305,178	355,348	434,297	1,772,907
95% confidence limits								
lower	508,008	65,297	139,818	51,796	271,046	145,040	310,885	1,009,884
upper	1,243,605	365,665	302,940	253,002	343,325	888,369	628,588	3,626,400
Exploitation rate (R/M)	3.9%	18.2%	8.7%	6.0%	11.3%	3.2%	4.8%	1.2%

* Fish tagged by ADF&G in Prudhoe Bay.

** Arbitrarily assigned the average of 1977 and 1978 size correction values.

***Arbitrarily assigned the average of 1978 and 1979 size correction values.

[†] Catch as of 23 November 1979 (i.e., near end of fishery for this year).

[††] A small but unknown number of fish identified as arctic cisco in the commercial catch were probably Bering cisco; however, Bering cisco were found only in our 1979 sub-sample of the commercial catch.

An adjustment was made for fish that were either too large or small to be vulnerable to the commercial fishery. This adjustment is shown in Fig. 22; it is calculated by adding the percentage differences at each size interval when sizes of tagged fish fall outside sizes of recaptured fish (from Ricker 1975). The number of tagged fish is then reduced by this percentage to determine the number of tagged fish susceptible to the fishery. For the 1976 ADF&G data, we assumed that a similar discrepancy in sizes occurred; the correction factors used in this case are indicated in Table 15.

Population estimates were calculated by the unbiased estimate of the Petersen mark/recapture formula (Chapman 1951, modified by Ricker 1975):

$$N = \frac{(M + 1)(C + 1)}{R + 1}$$

where N is the population size, M is the number of marked fish in Simpson Lagoon or Prudhoe Bay (corrected for size), C is the sample taken for census (i.e., the commercial catch), and R is the number of recaptured fish in the sample.

Apparent trends in populations of catchable fish suggest large-scale changes in anadromous cisco populations over the past several years (Fig. 23). Arctic cisco numbers appear to have dropped roughly 86% from 1976 to 1979 while least cisco increased 82% during the same period.

Are these figures or trends meaningful? On the one hand, the data suggest that recent changes have occurred in cisco stocks. This contention is supported by (1) large changes in the age structure of commercially caught arctic cisco (discussed in 'Additional Life-history Data for Fishes'), and (2) a reduction in the 1979 commercial catch of arctic cisco to only 25% of its average during the previous nine-year period; 1979 least cisco catches were 115% of their average over the same period (see 'Influence of Other Organisms'). On the other hand, these population estimates would be misleading if there were other significant sources of arctic cisco. In this case, there would be an open-ended system with mixtures of stocks, with the result that an unknown

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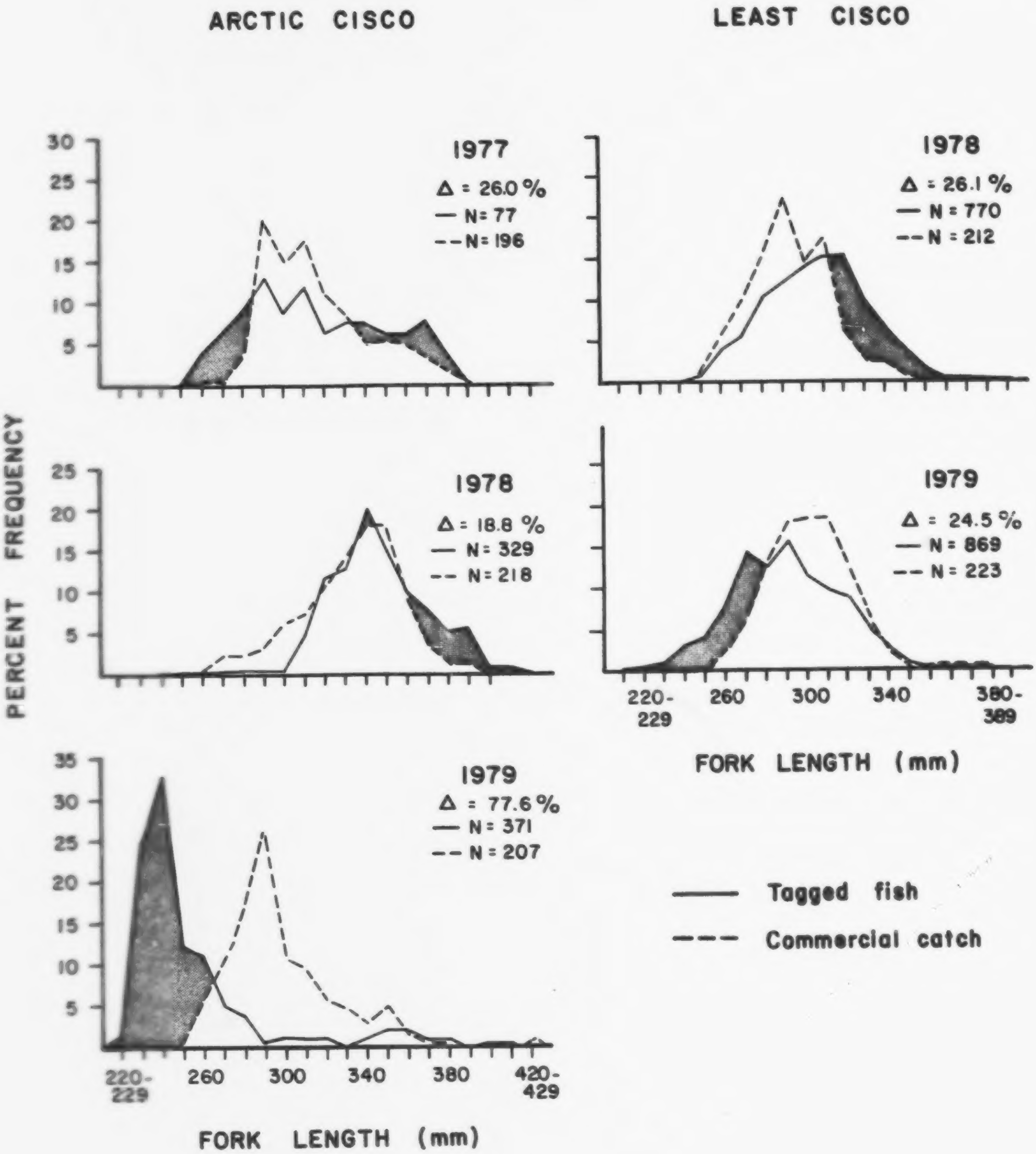

Figure 22. Comparison of sizes of arctic and least cisco tagged in Simpson Lagoon with sizes caught in the Colville Delta commercial fishery. Shaded areas represent the percentage (Δ) of tagged fish which were too large or small to be caught in the commercial fishery.

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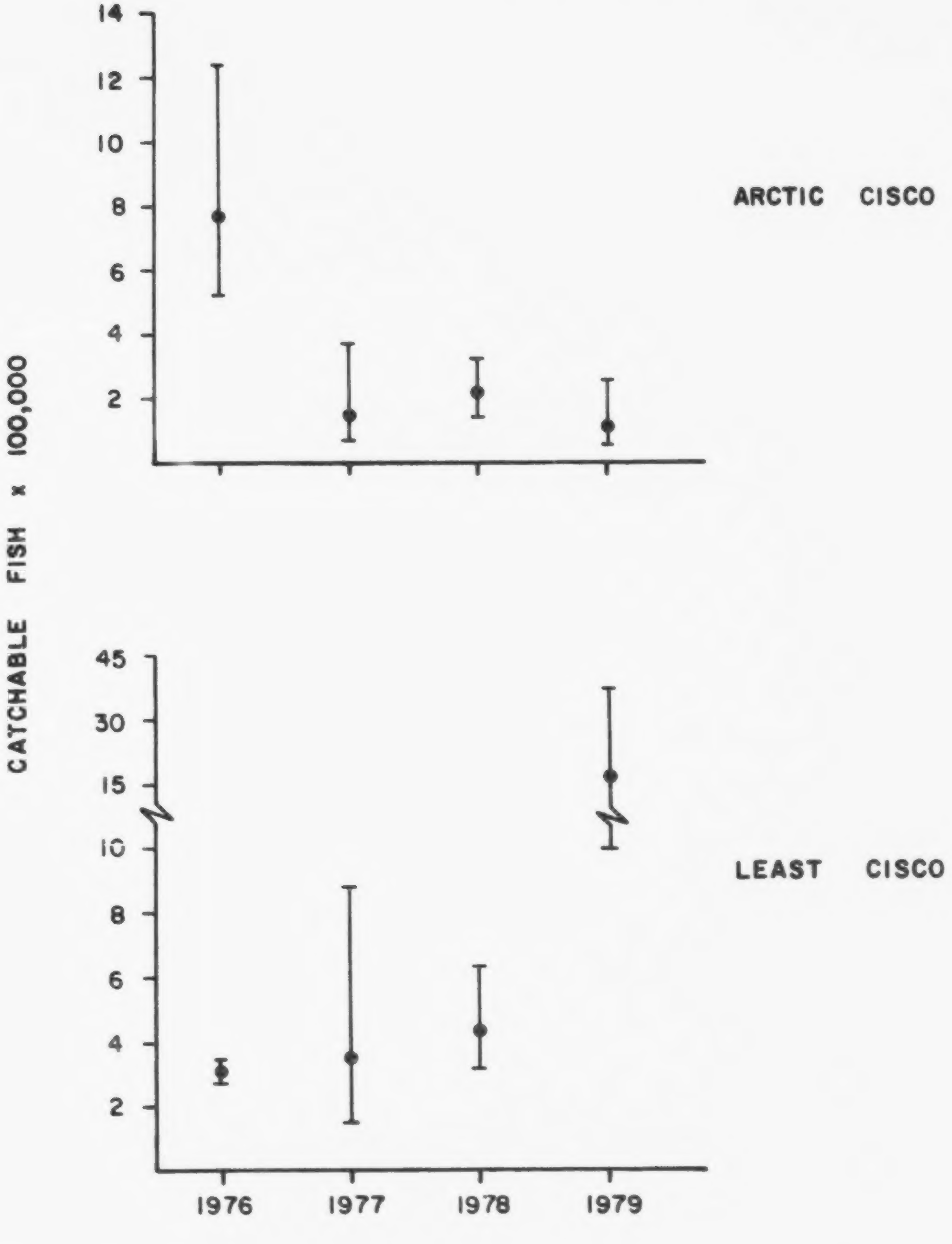

Figure 23. Estimates of "catchable" arctic and least cisco in the Colville River seagoing populations, 1976-1979. Bars indicate 95% confidence limits of mark/recapture estimates.

proportion of fish tagged in Simpson Lagoon would not be recoverable in the Colville Delta. Under such conditions our estimates of numbers of cisco in the Colville River would be too high.

In addition to suggesting that there might be large-scale population changes, the foregoing exercise points out that major data gaps regarding the distribution and biology of Alaskan Beaufort Sea ciscoes exist. Because of the importance of these fish in subsistence and commercial fisheries, we suggest that the information presented herein underscores the need for a better understanding of the biology of these species before any fisheries management or future monitoring programs for these fish can proceed. This problem is further discussed for arctic cisco in 'Additional Life-history Data for Fishes'.

Estimated Densities of Combined Species

In order to compare the available supply of invertebrate food resources in Simpson Lagoon with the total food requirements of all fish using the lagoon (see Griffiths and Dillinger 1980), we must (1) estimate how many fish are in the lagoon system and (2) find out how much food each fish consumes. In this section total fish numbers are estimated; food requirements are described later in 'Feeding Ecology'. The estimates of fish densities are based on several sources of information acquired in the field and presented in this report. Steps in the derivation of these somewhat rough estimates are as follows:

1. To calculate fish densities we separated fish into "large fish" and "small fish" categories because of obvious differences in the amount of food consumed by individuals in each size range and the suspected difference in food consumed per unit weight. Based on a preliminary review of life-history data, individuals in each size category were assigned a mean weight which is later used by Griffiths and Dillinger (1980) to calculate daily food intake: 470 g for large anadromous fishes (species combined: arctic cisco, least cisco, arctic char, broad and humpback whitefish); 15 g for small anadromous fish and marine species (species combined: fourhorn sculpin, arctic cod, arctic cisco, etc.).

2. To calculate fish densities, we stratified the lagoon by habitat, a 100-m-wide edge of the lagoon (7 km^2) and a lagoon-center habitat (153 km^2). We did this because fish concentrations were generally high along shoreline edges and low in the center portion (Figs. 11 and 13). The average abundance of large fish along mainland and lagoonside shorelines of the barrier islands was about 10 times greater than in the lagoon center (Table 5).

3. The density estimates for large anadromous fish were derived from beach seine data (Table 8). Density estimates were 0.006 large fish/m^2 along mainland shorelines and 0.002 large fish/m^2 along inside island shorelines. The average of these values, 0.004 large fish/m^2, was then assigned to edge habitats during the mid-summer period when fish were most abundant in the lagoon (see Fig. 17); 1/10 these values were used for central lagoon habitats (Table 16).

   Beach seine data appeared to underestimate densities of small fish because our fyke net data showed that small fish were many times more numerous than large fish. Therefore, densities of small fish were assumed to be 5-6 times greater (as indicated by fyke net catches) than densities of large fish (estimated from Table 4). Since our fyke net catch records showed that numbers of small fish, particularly the numerically dominant arctic cod and fourhorn sculpin, increased during the latter half of the summer (see Fig. 20), we have correspondingly changed our density estimates for small fish in Table 16. Densities are assumed to be lowest in early summer, increasing thereafter.

   Numbers of arctic cod inhabiting the lagoon during their approximate nine-day run in mid-August were estimated in three ways, all of which provide estimates between 12 and 27 million cod:

   a) The 61-m long fyke net sampled about 2% of the distance along a transect across the lagoon from Milne Point to Pingok Island (3300 m). During the cod run, the fyke net caught 124,200 cod. If we assume that the cod were uniformly distributed across the lagoon and that the efficiency of the fyke net was 50%, then the total run would be about 12 million cod.

Table 16. Estimated densities of small fish (15 g assumed weight) and large fish (470 g assumed weight) in two habitats in Simpson Lagoon, 1978.

Date	Small Fish (No./m^2x10^{-4})		Large Fish (No./m^2x10^{-4})	
	Edge*	Center**	Edge*	Center**
July 1-10	5	0.5	5	0.5
11-20	20	2	20	1.5
21-30	50	5	40	4
Aug. 1-10	50	5	40	4
11-20	1250	1200	40	4
21-30	70	7	40	4
Sept. 1-10	100	10	40	4
11-20	100	10	10	1
21-30	100	10	5	0.5

* 100 m wide band along shoreline edges (from Fig. 13) = 7 km^2.

**All of lagoon except edges = 153 km^2.

b) If we assume that the observed decline in invertebrate biomass during the cod run was largely caused by consumption by the cod, we get a somewhat similar estimate. Griffiths and Dillinger (1980) report that the standing crop of available food dropped 0.015 $g/m^2/day$ (ash-free dry weight) during the period 18-30 August 1978. Oldsquaw requirements were 0.0046 $g/m^2/day$ and large fish requirements were 0.0011 $g/m^2/day$, leaving a decrease of 0.01 $g/m^2/day$. The daily food requirement of each cod was 0.5 g wet weight or 0.06 g ash-free dry weight (8 g fish and 6% daily ration--see 'Feeding Ecology'). Using these values, there were approximately 27 million cod (27,000,000 cod x 0.06 g/cod ÷ 160,000,000 m^2 in lagoon = 0.01 $g/m^2/day$).

c) A final estimate is derived by extrapolations from the mark/recapture data of other species. In 1978, the total population of large arctic cisco entering coastal waters was estimated to be 239,928 fish (201,960 fish plus 18.8% due to size class corrections). If we assume that one half of these fish went eastward from the Colville River and the other half went westward (and there are no data to indicate this would be unreasonable), then 119,964 large arctic cisco passed through Simpson Lagoon in 1978. Of these, approximately 650 (0.5%) were caught in the fyke net. By similar calculations, we estimate that 0.8% of all least cisco were caught in the fyke net. If we assume that the fyke net caught a roughly equivalent portion of the arctic cod that passed through the lagoon (n = 124,200 cod caught in fyke net), then about 19 million cod were in the lagoon. Cod densities would then be 19 million cod/160 km^2 (0.12 cod/m^2) if the fish were equally dispersed throughout the lagoon. A density of 0.12 cod/m^2 is only 0.1% of that estimated for a school of cod observed at Prudhoe Bay which contained roughly 1-2 million fish (see 'Movements and Migrations').

It is clear that many of these assumptions and calculations are rough and so Table 15 must be interpreted accordingly. This exercise does, however, allow us to estimate the total amount of food consumed by fish in the lagoon. An analysis of food resources in relation to predation is presented by Griffiths and Dillinger (1980).

Feeding Ecology

The approach used in trophic studies was to examine major components of the food chain "from the top down", that is, from consumers to producers. Therefore, the nearshore food chain was examined by analyzing diets of principal vertebrate consumers and determining relationships between their nutritional requirements and the available food base. This section emphasizes the feeding habits of fishes, but an attempt is made to present a broader picture of vertebrate consumers in Simpson Lagoon. Large numbers of birds also feed in the study area and, together with fish, are the principal consumers of secondary production in the lagoon. (Use of the study area by marine mammals is incidental.)

Important species in Simpson Lagoon include five fishes (arctic cisco, least cisco, arctic char, arctic cod, fourhorn sculpin) and two bird groups (oldsquaw ducks, phalaropes). Another species, boreal smelt, is also included in food habit studies because these fish are abundant in winter. General aspects of consumers are compared in this section, but detailed accounts are presented elsewhere: fish ('Additional Life-history Data for Fishes') and birds (Johnson and Richardson 1980). The invertebrates in Simpson Lagoon are analyzed by Griffiths and Dillinger (1980) who also compare food requirements of fish and bird predators with prey resources.

The examination of fish feeding habits in Simpson Lagoon and surrounding waters is based on a sample of 703 stomachs of 7 species collected during summer and winter seasons 1977-1979 (Table 17). All summer samples are from Simpson Lagoon in the vicinity of Milne Point and Pingok Island. Winter samples are combined from a wider nearshore region shown in Figs. 6 and 7: arctic cisco, least cisco and fourhorn sculpin (Colville Delta, April/May 1978), fourhorn sculpin (Thetis Island, November 1978 and March/April 1979), boreal smelt (Simpson Lagoon and Thetis Island, November 1978) and arctic cod (Thetis Island to Narwhal Island, November 1978 and February 1979).

Table 17. Number of fish stomachs examined during summer and winter sampling periods.

Fish	Summer 1977	Winter 1977/8	Summer 1978	Winter 1978/9	Summer 1979	Total
Arctic cisco	55	40	57			152
Least cisco	51	23	27			101
Arctic char	60		17			77
Arctic cod	34		20	84	47	185
Fourhorn sculpin	65	9		45		119
Boreal smelt				39		39
Arctic flounder			31			31
					TOTAL	703

Since a fish's diet may change seasonally, a composite estimate of a species' diet was obtained by pooling and analyzing approximately equal numbers of samples collected during early, mid- and late periods of summer and winter, whenever possible (see 'METHODS'). Since the variety of food items in stomach contents of individual fish was low (Fig. 24) and the relative proportions of major food groups did not vary greatly (Fig. 25), a sample of 10-20 stomachs appeared adequate to describe the kinds and proportions of important food items consumed during any one sampling period. It is therefore felt that the pooled data from the three summer and three winter periods (depending on availability of specimens) reflect the general diets of each fish species in nearshore waters. Size classes of fish used in dietary analyses were those most common in the study area--in general, medium- to large-sized fish of most species prevailed in catches and in samples used for stomach analyses (Table 18).

Trophic Spectrum

In order to identify which components of possible food sources are utilized by fish, we have categorized the invertebrates and other potential food groups according to functional habitat or taxonomic units. This list includes food groups known to be important to fish in the study area and, for completeness, several basic food groups which are eaten by fish in non-arctic areas. This range of foods potentially available to fish is called a trophic spectrum (Darnell 1961) and the one used here is a slightly modified version used by Cailliet et al. (1978).

Five general sources of food are recognized: (1) water column organisms (including fish and zooplankton), (2) mobile epibenthos (crustacea and polychaetes), (3) sedentary epibenthos (crustacea, molluscs, tunicates and eggs from invertebrates or fish), (4) infauna (worms such as polychaetes, and molluscs) and (5) flora (algae, vascular plants and detritus).

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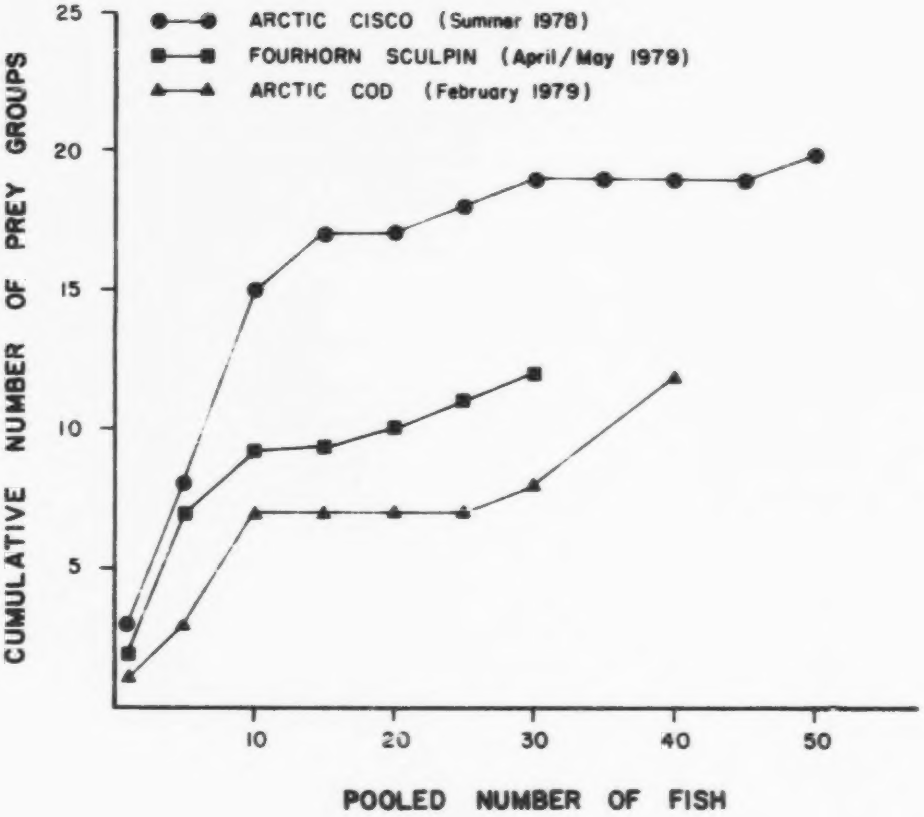

Figure 24. Cumulative number of prey species or groups in pooled fish stomachs.

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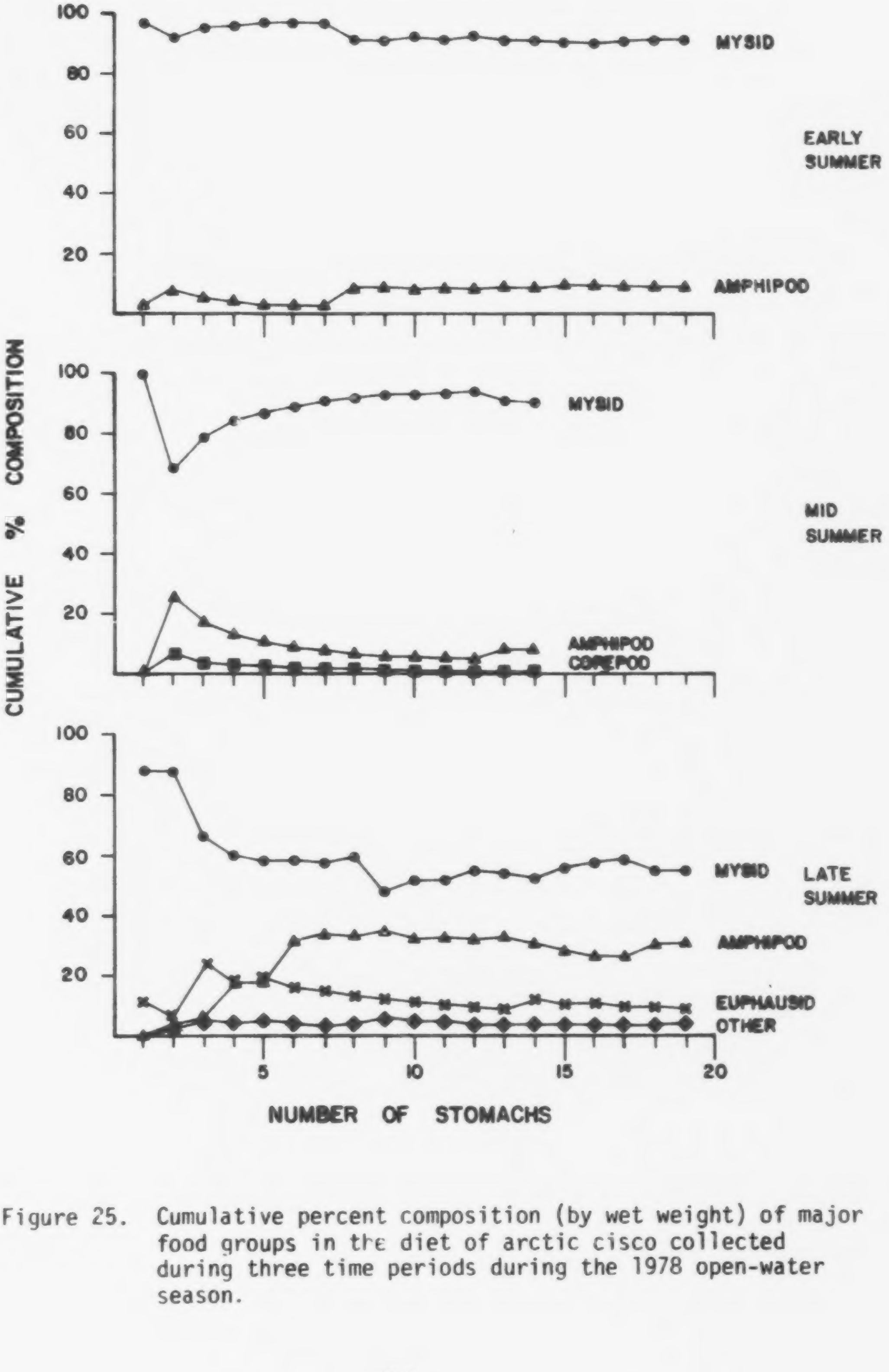

Figure 25. Cumulative percent composition (by wet weight) of major food groups in the diet of arctic cisco collected during three time periods during the 1978 open-water season.

Table 18. Sizes of fish used in food habit studies.

Fish	Summer 1977			Winter 1977/78*			Summer 1978			Winter 1978/79			Summer 1979		
	n	x̄ (range)	SD	n	x̄ (range)	SD	n	x̄ (range)	SD	n	x̄ (range)	SD	n	x̄ (range)	SD
Arctic cisco	55	360 (290-410)	29	24	317 (226-368)	26	57	342 (205-419)	49						
				16	173 (148-204)	18									
Least cisco	51	307 (211-412)	35	23	267 (146-357)	21	27	302 (222-366)	37						
Arctic char	60	475 (236-690)	142				17	331 (264-609)	95						
Arctic cod	34	160 (93-221)	35				20	109 (91-139)	11	84	125 (50-253)	29	47	92 (60-155)	25
Fourhorn sculpin	65	150 (56-248)	52	9	193 (175-265)	66				45	184 (130-253)	32			
Arctic flounder	31	216 (148-265)	32												
Boreal smelt										39	251 (190-305)	30			

*Colville Delta (April/May 1978).

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When the trophic spectrum is examined, it is apparent that the diets of vertebrate consumers (including birds) are surprisingly similar (Fig. 26). A single category, mobile epibenthic crustacea, is by far the most important food group for most fish and birds. This group accounts for over 90% of the diet for arctic cisco, least cisco, arctic char, arctic cod and oldsquaw. The remaining three predators feed heavily on this food category (44-64% of the diet) but additional preferences are also apparent. Two feed on "water column" organisms--boreal smelt eat fish (41%) and phalaropes eat zooplankters (36%). One predator feeds on "sedentary epibenthos"--fourhorn sculpin eat a bottom-crawling isopod (44%).

What is conspicuously absent among vertebrate consumers in the lagoon are species that rely on infaunal organisms, sedentary benthos or flora. This apparent void is only partly explainable by the reduced variety of organisms inhabiting rigorous environments like Simpson Lagoon. Harsh physical features of the lagoon (shallow and wind-churned waters, widely fluctuating temperatures and salinities, lack of solid substrates for attachment of plants or animals, and winter ice conditions) provide unsuitable conditions for all but a few kinds of organisms. There are, for example, no vascular plants growing in the lagoon and very little macrophytic algae is present. However, a reduced variety of species does not, by itself, account for the observed reliance on mobile epibenthic crustaceans. Some infaunal organisms (bivalve molluscs, polychaetes) and sedentary epibenthos (isopods, tunicates, stalked polychaetes and hydroids) are abundant but little utilized. Their biomass in Simpson Lagoon is similar to the biomass of the mobile epibenthic crustaceans:

	g/m^2 ash-free dry weight
infauna and sedentary epibenthos	0.5*-2.1**
mobile epibenthos	0.3-2.5***

* From Griffiths and Dillinger (1980) for bivalves excluding shells.

** Recalculated from Crane (1974) for ash-free dry weight of worms, tunicates and bivalves excluding shells; deep lagoon stations, Aug. 1971.

***From Griffiths and Dillinger (1980); deep lagoon stations, August 1977 and August 1978.

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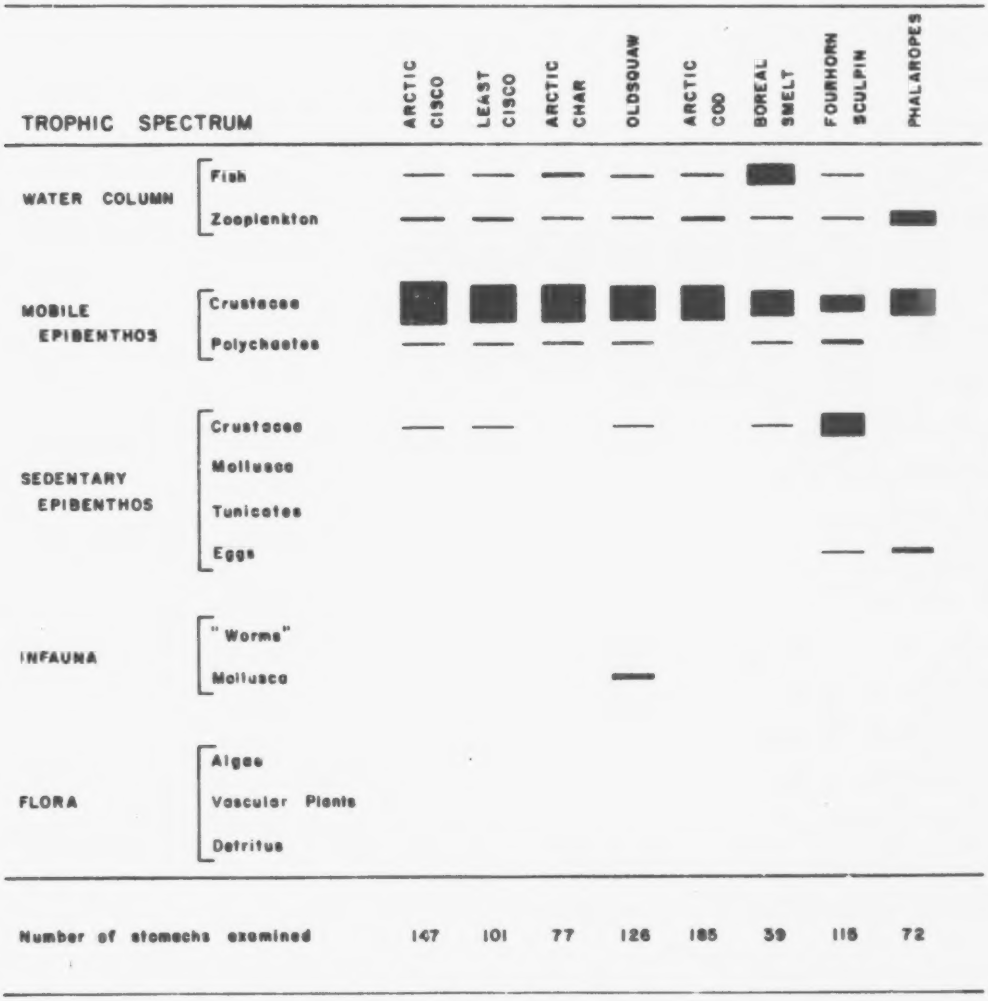

Figure 26. Trophic spectrum of vertebrate consumers in Simpson Lagoon for combined dates and locations, 1977-1979. For each species, proportions of foods in the diet are indicated by bands; the sum of heights of all bands within each spectrum equals 100%.

It is understandable that some infaunal organisms are not vulnerable to predation by shorebirds due to lack of tidal exposure, but this potential food source appears accessible to diving ducks and fish. However, only oldsquaw eat them (approximately 10% of diet). A slight increase in use of infauna is conceivable if the polychaetes classified as "epibenthos" were actually "infauna" when eaten, but indirect evidence--the lack of virtually any detrital material in fish or bird stomachs--suggests this is not the case.

Even the arctic flounder, a fish which sometimes eats infaunal organisms (Andriyashev 1954), feeds primarily on amphipods and isopods in Simpson Lagoon. No bivalves were found in their stomachs, and polychaetes accounted for only 3% of their diet.

If alternate sources of food are plentiful, there are energy-efficiency reasons why a consumer might not seek infaunal organisms as part of its overall feeding strategy:

1. buried organisms may be hard to find, especially in shallow lagoon waters (less than 2 m deep) where the infauna is very sparse (Crane 1974; Broad 1978), or
2. prey size-classes vulnerable to predation may not be abundant or available at suitable depths.

An alternate food source is indeed available--the mobile epibenthic crustaceans represented by mysids and amphipods in Simpson Lagoon. We suspect that these organisms are numerous enough to satisfy the food requirements of most predators, thereby accounting for the observed reduction in partitioning of food resources among consumers. This contention will be addressed further in the 'GENERAL DISCUSSION' ('Implications of Feding Ecology').

General Food Habits and Food Chain

Mysids and amphipods are the most significant foods of fish in Simpson Lagoon. During the 1977-1979 open-water seasons, these invertebrates accounted for 90-99% of all identifiable food ingested by four of the five species examined (Table 19). Copepods, isopods and smaller fish are usually of secondary importance and the remaining groups

Table 19. Food groups eaten by lagoon fishes during the open-water period, 1977-1979.

	% Composition (wet weight)									
	Arctic Cisco		Least Cisco		Arctic Char		Fourhorn Sculpin	Arctic Cod		
Food Item	1977	1978	1977	1978	1977	1978	1977	1977	1978	1979
mysid	70	87	69	66	16	89	10	88	38	59
amphipod	25	11	21	33	78	4	81	9	18	39
copepod	4	*	9	*	1	*	*	2	44	1
isopod	*	*	*	-	*	-	6	-	-	-
fish	-	*	*	*	2	6	3	*	-	-
other taxa**	*	*	*	*	3	*	*	*	-	*
No. Stomachs*** Examined	55	52	51	27	60	17	65	34	20	47

* <1.0%.

** Includes: polychaetes, bivalves, pteropods, cumaceans, chaetognaths, hydroids, decapods, euphausiids.

***Stomachs containing food.

(polychaetes, euphausiids, decapods, bivalves, pteropods, cumaceans, chaetognaths and hydroids) are incidental food items. For the two cisco species, proportions of the food groups eaten are generally similar between years of study. Large changes in diet are noted for the char and cod, however. Char switched from amphipods in 1977 to mysids in 1978, and arctic cod ate more copepods and fewer mysids in 1978 than 1977.

The fish continued feeding through the winter months. Mysids and amphipods were again heavily utilized by fish but other food groups were also important (Table 20). Fourhorn sculpin eat mostly isopods, and boreal smelt eat fish.

A generalized food chain for Simpson Lagoon is shown in Fig. 27. The chain is very short. Fish and birds feed primarily on epibenthic invertebrates (mysids and amphipods), and these invertebrates feed directly or indirectly on phytoplankton and detritus (Schneider and Koch 1979). Schell's (1979) isotopic studies indicate that approximately 60-70% of the carbon in fish tissues originates from modern marine primary production. Terrestrially-derived carbon (from river runoff and shoreline erosion) accounts for the remainder.

Principal Prey

Major food groups, mysids and amphipods, have been identified to the species level. For one predator, arctic cisco, the list of prey species is long, although only a few species form the bulk of the diet (Table 21). *Apherusa glacialis* and *Onisimus glacialis* account for 95% of the total weight of identified amphipods, and *Mysis litoralis* and *M. relicta* account for 100% of the total weight of identified mysids. A vast number of small mysids (*Mysis* sp.) were also eaten and it seems a safe assumption that these are the young of the identified species. A summer average of 4,092 of these small mysids was found in each arctic cisco stomach, but most ($\bar{x}$ = 13,100 per stomach, range 1,400-45,000) were eaten in spring when newly-released mysids were abundant.

In order to compare foods of fish and birds in more detail, prey items have been analyzed in the following manner. Food items ingested by each predator are listed as percent wet weight of identifiable

Table 20. Winter foods of nearshore fishes, 1977-1979.

	% Composition (wet weight)					
	Colville Delta			Nearshore Waters		
Food Item	Arctic Cisco	Least Cisco	Fourhorn Sculpin	Fourhorn Sculpin	Arctic Cod	Boreal Smelt
mysid	*	-	-	3	93	39
amphipod	99	100	31	5	3	20
isopod	-	-	60	78	-	*
fish	-	-	-	*	2	40
fish eggs	-	-	9	5	-	-
polychaete	*	-	-	2	-	*
other taxa	*	-	-	6	2	*
No. stomachs examined**	40	23	9	45	84	39

* <1.0%

**Stomachs containing food.

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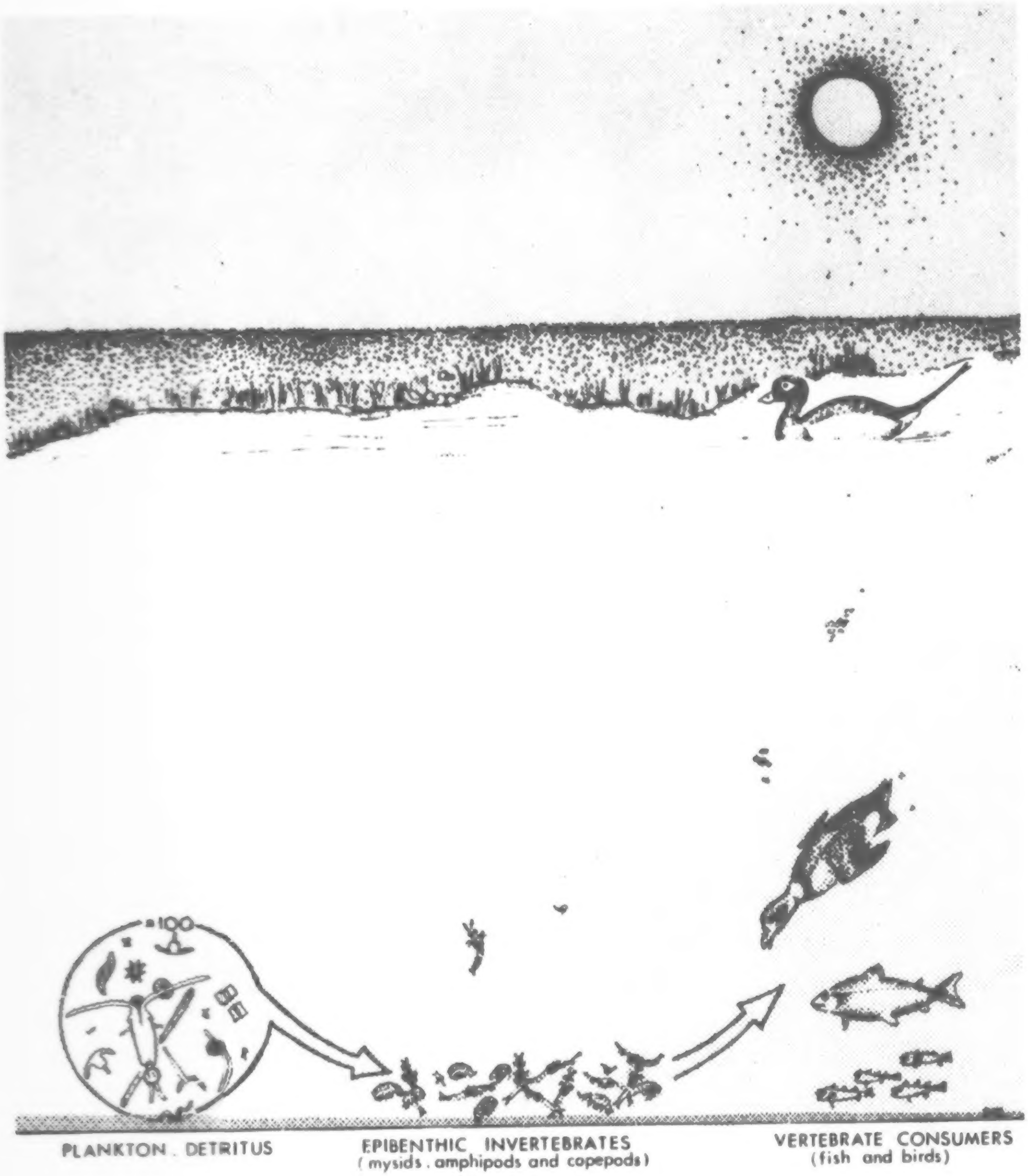
PLANKTON . DETRITUS
EPIBENTHIC INVERTEBRATES
(mysids, amphipods and copepods)
VERTEBRATE CONSUMERS
(fish and birds)

Figure 27. Nearshore food chain.

Table 21. Species composition of amphipods and mysids eaten by arctic cisco, summer 1977.

	Summer Average (n = 55)		
Food Item	Number	Weight (g)	% Wet Weight Identified Spp.
A. MYSIDS			
Mysis litoralis	136.6	1.32	78.1
Mysis relicta	73.3	0.37	21.9
Mysis sp.	4092.1	3.07	
			100%
B. AMPHIPODS			
Apherusa glacialis	111.2	0.71	62.6
Onisimus glacialis	94.1	0.37	32.6
Onisimus	96.8	0.46	
Unidentified gammarid	48.5	0.10	
Gammarus setosus	2.4	0.03	2.6
Unidentified amphipod	2.8	0.02	
Acanthostepheia behringiensis	0.8	*	0.6
Onisimus litoralis	0.6	*	0.5
Parathemisto libellula	0.3	*	0.6
Gammaracanthus loricatus	0.2	*	0.3
Acanthostepheia incarinata	0.1	*	**
Onisimus nanseni	0.7	*	**
Gammarus sp.	0.3	*	
Weyprechtia pinguis	0.3	*	**
Pontoporeia affinis	0.1	*	*
Apherusa sp.	0.1	*	
Unidentified lysianassid	**	*	
Monoculodes sp.	**	*	*
Unidentified hyperiid	**	*	
Unidentified caprellid	**	*	
			100%

* < 0.01

**< 0.1

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contents. Then, on the assumption that most of the material not identified to the species level, e.g., "gammarid amphipods", is actually the remains of the identified gammarid species, the unidentified gammarids have been allocated to the prey species known to be present in the proportions already determined for that predator. Laboratory taxonomists who identified these samples felt that the assumption is reasonable, although a small percentage of the broadly-based categories contained uncommon species. For the present uses of these data, it is felt that this procedure provides a better base for comparison than either deleting or retaining all broadly-based categories for mysids and amphipods. In any event, contributions of the broadly-based categories are generally small (usually less than 5% of contents). A list of prey for each consumer is presented in Table 22. Principal prey are arbitrarily defined as species or groups which constitute 10% or more (by wet weight) of the total diet.

Principal prey of vertebrate consumers in Simpson Lagoon consist of two mysid species, six amphipod species and four additional taxonomic groups--copepods, isopods, bivalves and fish (Fig. 28). Several interesting points emerge in comparing diets among the consumer.

1. The number of principal prey eaten by the common vertebrate species is low (2-7) during any single sampling period, reflecting considerable dietary overlap among predators.
2. Two mysids, *Mysis litoralis* and *M. relicta*, are clearly the favored prey in the system. Of the 40 entries listed in Fig. 28 for summer and winter, the breakdown of principal prey was:

	%
Mysis litoralis	30
Mysis relicta	22
Onisimus glacialis	15
Pontoporeia affinis	8
Apherusa glacialis	5
Gammarus setosus	3
Pontoporeia femorata	3
Gammarocanthus loricatus	3
copepods	3
isopods	5
bivalves	3
fish	3

3. The common vertebrate species tended to eat similar prey during the summer but different prey in winter.

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Table 22. Modified list of foods in fish and bird stomachs whereby broadly-based categories (e.g., "unidentified gammarid amphipods") are converted to existing proportions of taxonomically-appropriate prey already listed (see Text). Abbreviations: ARCS (arctic cisco), LSCS (least cisco), CHAR (arctic char), ARCD (arctic cod), FHSC (fourhorn sculpin), OLDS (oldsquaw), PHAL (phalaropes), BORS (boreal smelt).

	% Composition (Wet Weight)																				
	Summer 1977						Summer 1978						Summer 1979	Winter 1977-78			Winter 1978-78		
Food Item	ARCS	LSCS	CHAR	ARCD	FHSC	OLDS	ARCS	LSCS	CHAR	ARCD	OLDS	PHAL	ARCD	ARCS	LSCS	FHSC	FHSC	ARCD	BORS
Mysis litoralis	54.6	16.4	12.0	12.1	4.6	34.1	54.1	31.2	68.4	10.2	70.8	2.3	40.1	*	-	-	3.7	81.5	34.7
Mysis relicta	15.2	52.7	3.5	75.9	5.1	33.5	32.8	35.1	20.9	28.0	8.9	-	19.3	-	-	-	0.7	11.7	4.4
Apherusa glacialis	10.8	1.0	14.6	-	*	*	1.3	-	-	-	-	6.7	0.6	-	-	-	-	-	-
Haliragus mixtus	-	-	-	-	-	-	1.6	-	*	-	-	-	*	-	-	-	-	0.4	0.3
Onisimus glacialis	12.4	8.0	11.5	7.0	47.8	8.0	6.7	24.8	2.7	17.5	10.4	82.4	35.4	-	-	-	0.8	1.5	0.5
Gammarus setosus	1.9	2.7	45.0	0.1	16.1	1.7	*	0.5	1.3	-	0.8	-	2.6	-	-	-	-	-	0.6
Parathemisto spp.	0.1	*	5.0	1.8	4.2	4.9	1.7	-	*	-	0.3	-	-	-	-	-	-	-	-
Pontoporeia affinis	-	0.6	0.3	0.2	0.5	-	*	7.6	*	0.3	0.1	-	0.5	99.5	100	30.6	3.2	0.8	0.1
Pontoporeia femorata	-	1.9	0.2	-	0.3	-	-	-	-	-	*	-	*	*	-	-	4.2	0.4	17.6
Gammaracanthus loricatus	0.2	7.0	1.4	0.3	11.7	1.2	*	0.3	0.3	-	0.7	6.7	*	-	-	-	-	*	0.6
Copepod	4.5	8.7	1.3	2.1	*	1.2	0.6	-	-	44.0	*	-	0.9	-	-	-	*	0.4	0.2
Isopod	0.3	0.1	0.2	-	6.1	2.7	*	0.2	0.1	-	0.9	1.9	-	-	-	60.2	73.5	-	0.1
Cumacean	*	0.6	0.2	-	*	-	*	*	*	-	0.1	-	*	-	-	-	0.1	*	*
Euphausid	*	-	2.8	0.5	-	-	0.7	-	-	-	0.1	-	0.4	-	-	-	-	-	-
Fish	-	0.3	1.6	-	3.3	2.7	0.2	0.2	5.8	-	0.4	-	-	-	-	-	0.7	1.5	40.5
Eggs	-	-	-	-	*	-	-	-	-	-	-	-	-	-	-	9.2	3.1	*	*
Bivalves	-	-	-	-	-	9.6	-	-	-	-	6.2	-	-	-	-	-	-	-	-
Polychaetes	-	-	*	-	*	-	-	-	0.2	-	*	-	-	*	-	-	9.2	-	0.2
Miscellaneous taxa	*	0.2	0.3	*	0.2	-	0.2	-	-	-	0.3	-	-	0.4	-	-	0.7	1.9	-
No. Stomachs	55	51	60	34	65	54	52	27	17	20	72	26	47	40	23	9	45	84	39

*<0.1%

PRINCIPAL PREY		SUMMER 1977						SUMMER 1978						WINTER 1977/8			WINTER 1978/9		
		A. CISCO	L. CISCO	A. CHAR	F. SCULPIN	A. COD	OLDSQUAW	A. CISCO	L. CISCO	A. CHAR	A. COD	OLDSQUAW	PHALAROP	A. CISCO	L. CISCO	F. SCULPIN	F. SCULPIN	A. COD	B SMELT
MYSIDS	*Mysis litoralis*	X	X	X		X	X	X	X	X	X	X						X	X
	Mysis relicta	X	X			X	X	X	X	X	X							X	
AMPHIPODS	*Apherusa glacialis*	X		X															
	Onisimus glacialis	X		X	X				X		X	X	X						
	Gammarus setosus			X	X														
	Gammaracanthus loricatus				X														
	Pontoporeia affinis													X	X	X			
	Pontoporeia femorata																		X
	BIVALVE						X												
	COPEPOD										X								
	ISOPODS															X	X		
	FISH																		X

Figure 28. Principal prey (≥ 10% by weight) of nearshore fishes and birds.

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The degree of similarity between predator diets was calculated by the Morisita overlap index (Horn 1966) which compares the relative proportions of prey groups in the diets of the predators. During both summers of study, dietary overlap was high even when analyzed at the species level of detail for major prey (Table 23). Of the 15 possible comparisons of predators during each summer , 27% (in 1977) and 40% (in 1978) showed that predators exploited similar ($C \geq 0.6$) species or groups of food organisms. In 1977, overlap was very high between oldsquaw and three fishes (arctic cisco, least cisco, arctic cod) and between least cisco and arctic cod largely due to the importance of *Mysis litoralis* and *M. relicta* in their diets (Table 22). Overlap between consumers was higher the following summer. Diets of oldsquaw and the anadromous fishes were all similar, again reflecting the heavy usage of the two mysid species which dominate the lagoon's epibenthic community of invertebrates (Griffiths and Dillinger 1980).

Diets of some predators showed little annual variation. Arctic cisco (C = 0.94), least cisco (C = 0.84) and oldsquaw (C = 0.74) each ate essentially the same food items in the same proportions during both summers. Diets of arctic char were dissimilar between years (C = 0.26) and arctic cod diets varied during three summer sampling periods:

	1977	1978	1979
1977	-		
1978	0.54	-	
1979	0.48	0.50	-

In winter, fish changed their diets as indicated by very low overlap values obtained in a summer-winter comparison: arctic cisco (C = 0.0), least cisco (C = 0.06), fourhorn sculpin (C = 0.12). Arctic cod also ate different foods between summer 1978 and winter 1978-79 (C = 0.24) but similar foods between winter 1978-79 and summer 1979 (C = 0.71). The two ciscoes overwintering in the Colville Delta fed almost exclusively on a single amphipod species, *Pontoporeia affinis*, accounting for an overlap of 1.00 at this time:

Table 23. Indices of dietary overlap among fish and birds in Simpson Lagoon calculated by the Morisita overlap index (Horn 1966).

	Summer 1977					
	arctic cisco	least cisco	oldsquaw	arctic char	fourhorn sculpin	arctic cod
Arctic cisco	-					
Least cisco	.55	-				
Oldsquaw	.82	.84	-			
Arctic char	.36	.22	.29	-		
Fourhorn sculpin	.15	.28	.30	.52	-	
Arctic cod	.40	.93	.72	.12	.18	-

	Summer 1978					
	arctic cisco	least cisco	oldsquaw	arctic char	arctic cod	phalaropes
Arctic cisco	-					
Least cisco	.87	-				
Oldsquaw	.90	.68	-			
Arctic char	.96	.73	.97	-		
Arctic cod	.45	.58	.32	.28	-	
Phalaropes	.12	.43	.06	.29	.17	-

	arctic cisco	least cisco	fourhorn sculpin
arctic cisco	-		
least cisco	1.00	-	
fourhorn sculpin	0.42	0.42	-

The sculpin at this location also ate *P. affinis* but overlap values were low because it ate isopods as well.

In nearshore coastal waters, overlap in winter diets was variable--very low between fourhorn sculpin and other fishes, but roughly similar between arctic cod and boreal smelt due to their use of mysids:

	arctic cod	boreal smelt	fourhorn sculpin
arctic cod	-		
boreal smelt	0.59	-	
fourhorn sculpin	0.05	0.06	-

It is difficult to generalize about the winter data. Dietary overlap was variable but seems lower at this time than in summer, suggesting a greater partitioning of food resources. This is apparent in coastal waters where the three commonly captured fishes relied in large part on different prey: arctic cod (mysids), fourhorn sculpin (isopods), boreal smelt (fish and mysids). However, the ciscoes and sculpin in the Colville Delta all relied heavily on one prey item.

Selectivity

The diet of arctic cisco was compared with the available food supply to determine if the fish selected particular prey species. Ivlev's (1961) electivity index was used for this purpose:

$$E = \frac{r_i - p_i}{r_i + p_i}$$

where E is the measure of electivity, r_i the relative abundance of prey item i in the gut (as a percentage of wet weight) and p_i the relative abundance of the same prey item in the environment. The index has a possible range of -1 to +1, with negative values indicating avoidance or inaccessibility of the prey item, zero indicating random selection from the environment and positive values indicating active selection.

The results indicate that arctic cisco select the two mysid species which form the bulk of their diet, but the strength of this selection is not great as indicated by low overall E values of 0.20 and 0.21 (Table 24). This suggests that mysids were abundant enough to meet the needs of the arctic cisco without the fish having to actively seek them out much beyond their relative proportion among the lagoon's epibenthos. That is, if mysids had been rare, fish would have to strongly select for them (high E) because mysids account for nearly 75% of their diet, but this was not the case.

It is interesting that one common epibenthic species, *Onisimus glacialis*, is either avoided by or inaccessible to arctic cisco (electivity index = -0.78). Fish may indeed dislike this amphipod, since we watched arctic char in a field aquarium routinely spit them out after attacking them. However, *O. glacialis* often burrows into the lagoon bottom, so we suspect that the inaccessibility of this amphipod definitely contributes to the low E value.

Do some arctic cisco select only mysids while others select amphipods? The answer is no, since virtually all stomachs examined contained both groups together (92% of 52 stomachs). In fact, very few fish (6%) ate only one food group (i.e., major taxonomic groups--mysids, amphipods, copepods etc.) while 46% had three or more groups in their stomachs at one time.

Throughout the summer, arctic cisco tend to eat the sizes of prey available as opposed to catching only particular size groups (Fig. 29). This is particularly evident for *Mysis litoralis* and *Onisimus glacialis*, but less so for *Mysis relicta*--arctic cisco appear to eat the smaller sizes of this species. In general, a high degree of overlap (Horn 1966) is apparent between the sizes eaten by arctic cisco and the sizes available in Simpson Lagoon:

Table 24. Comparison of proportions of mysids and amphipods in diets of arctic cisco and in the lagoon. Collection dates and sample sizes are indicated in Fig. 29.

		Electivity Index				
		Station 1				Stations 1-5
Prey	% of Total Diet	early summer	mid-summer	late summer	summer combined	summer combined
Mysis litoralis	47	0.07	0.53	0.19	0.30	0.20
Mysis relicta	29	0.12	-0.44	0.10	0.11	0.21
Unidentified mysids	8	0.23	-1.00	-0.10	0.36	0.58
Onisimus glacialis	4	-0.47	-0.95	-0.99	-0.77	-0.78
Parathemisto spp.	1			1.00	1.00	0.69
Halirages mixtus	1			1.00	1.00	0.52
Apherusa glacialis	1			1.00	1.00	0.86
Gammarus setosus	*		-1.00		-1.00	-1.00
Pontoporeia affinis	*	-1.00	-1.00	-0.99	-1.00	-1.00

*< 0.1.

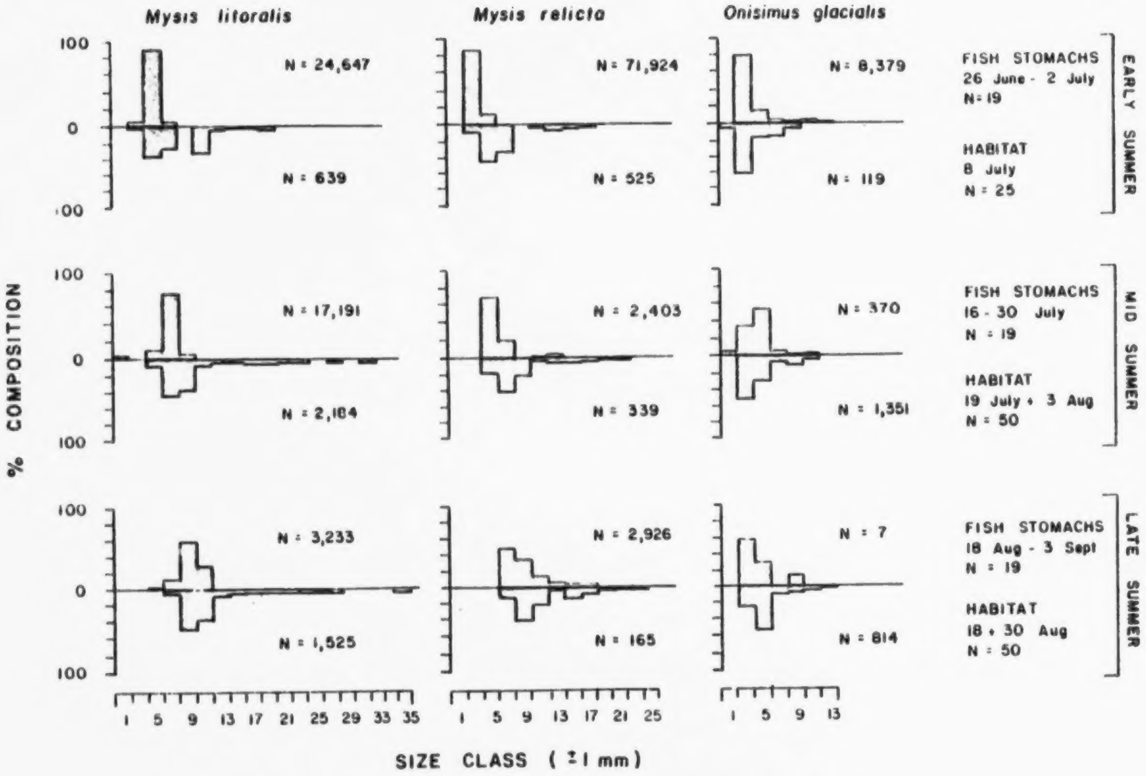

Figure 29. Comparison of prey sizes eaten by arctic cisco with prey sizes available in Simpson Lagoon, summer 1978. Invertebrate species were sampled by drop net at each lagoon station (5 samples/station/date; see Griffiths and Dillinger 1980). N = number of invertebrates in combined samples (but not number measured due to sub-sampling procedures).

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Species	Overlap Index for Prey Size Class early summer fish diet	 mid-summer fish diet	 late summer fish diet
Mysis litoralis	0.61	0.75	0.96
Mysis relicta	0.26	0.55	0.76
Onisimus glacialis	0.94	0.86	0.77

Of these nine possible comparisons, 78% indicate broad overlap ($C \geq 0.60$).

If we extend this comparison to other consumers and their prey, the results are generally similar to those shown for arctic cisco. The trend is for a high degree of overlap between the prey sizes available and the prey sizes eaten (Table 25). Of the available season/prey species comparisons, most indicated a broad overlap:

Species	% of Comparisons with $C \geq 0.6$
least cisco	80
arctic cisco	67
oldsquaw	75

Though the overall overlap for oldsquaw was high, it appears that this result does not apply to the mid-summer period (19 July, Table 25). At this time, oldsquaw selectively ate large prey items, thus accounting for a very low overlap index. Johnson and Richardson (1980) also report that oldsquaw tended to eat the larger size classes of prey available.

Feeding Areas

Based on the distribution of fishes in the study area (see 'Habitat Utilization'), it is reasonable to conclude that fish, particularly the anadromous species, feed primarily in brackish nearshore waters since few were caught in offshore marine waters. It is also probable that most fish feed within a narrow band along mainland and island shorelines, since catch rates are highest in these habitats throughout the summer. If this were not the case, and fish darted into either offshore waters or the lagoon center to forage, catch rates in these areas would be much higher than recorded. Furthermore, it is reasonable to assume that fish

Table 25. Comparison of prey sizes available in lagoon with prey sizes eaten by various fish and birds using the Morisita overlap index (Horn 1966). Collection dates of fish and birds were selected for those within one week of the invertebrate sample dates. The number of stomachs examined varies according to the occurrence of the prey species present.

	Overlap Indices during Invertebrate Sampling Periods (1978)							
	8 July	19 July			3 August		18 August	30 August
	Least Cisco	Least Cisco	Arctic Char	Oldsquaw	Arctic Char	Oldsquaw	Oldsquaw	Oldsquaw
Mysis litoralis	-	.92	.68	.12	.86	.90	.82	.83
Mysis relicta	.15	.66	.07	.21	.21	.64	.85	.71
Onisimus glacialis	.88	.75	.78	.37	.87	.65	.75	.82
No. Stomachs with Prey Species	17-18	6	5-8	8-14	6-9	5-12	5-13	10-13

selected for diet analysis actually fed in Simpson Lagoon since their average rate of movement in coastal waters (see 'Residency Time in Simpson Lagoon') and rate of food passage through their gut (see 'Gastric Evacuation Rate') suggests that most fish probably ate within 3 km and 24 h of the time and place of capture.

Beyond these generalizations, little is known about specific locations that might be important feeding areas for fish. We do not know, for example, whether fish feed throughout this nearshore zone or in specific habitats where food organisms might actively or passively concentrate.

It is not clear why fish feed in this restricted shallow zone because the distribution of fish does not reflect the distribution of prey. The food supply is much more abundant in the center of the lagoon where fish numbers are relatively low. Griffiths and Dillinger (1980) report that *Mysis litoralis*, a major prey item for fish, is significantly more abundant (approximately 3-8 times) in the center of the lagoon (Stations 2, 3 and 4) than along the lagoon edges (Stations 1 and 5).

In addition to having lower prey densities, shallow waters are generally more turbid than central lagoon waters. If the fish are visual feeders, it might be expected that turbid waters would hinder their feeding, but this apparently is not the case, since some fish caught in turbid waters have full stomachs and some caught in clear water have empty stomachs. While this may be an artifact of sampling, it may also indicate that fish feed successfully in turbid waters, perhaps due to a reduced escape response of the prey (an escape response by mysids was observed in field aquaria).

Feeding areas of birds differ somewhat from those of fish. Phalaropes tend to feed very close to shore, often within 10 m of the shoreline, and they make more use of island shorelines than do fish. Oldsquaw ducks have been observed feeding throughout the lagoon and in offshore marine areas, but most feeding occurs in open waters of the lagoon rather than close to the shoreline (i.e., not within 500 m).

Food Requirements of Fish

To examine the relationship between consumers' food requirements and the available food in Simpson Lagoon, information on the following three points is needed:

1. number of fish in the lagoon (see 'Population Numbers'),
2. amount of food a fish eats each day (this section), and
3. functional response of fish to changes in prey density.

Points 1 and 2 allow a calculation of the daily food requirements of fish in the lagoon. This value, when compared to the food supply available, indicates the proportion of food eaten. Point 3, which is an experimentally difficult project, was not addressed in this study; consequently, it is difficult to predict the effect of a large reduction in the standing crop of mysids. That is, even though there might appear to be an adequate food supply left in the lagoon should the density of prey drop, a level will eventually be reached whereby the predators would not find or catch an adequate amount to meet their needs. For present purposes, however, estimates of Points 1 and 2 and the available food supply suggest that the prey density in the Simpson Lagoon ecosystem are far above the levels at which fish might have difficulty acquiring enough food (see 'Implications of Feeding Ecology' in 'GENERAL DISCUSSION').

This section discusses the food requirements of an important fish species in Simpson Lagoon, the arctic cod. The amount eaten each day (daily ration) by an average arctic cod was estimated using three types of information obtained under field conditions during the summer of 1978; these were (1) the proportion of the day that the fish spent feeding (feeding periodicity), (2) the rate at which food passed through their stomachs (gastric evacuation rate), and (3) the amount of food in their stomachs at various times of day. Experiments were conducted using sizes of juvenile arctic cod representative of those found in Simpson Lagoon. Size ranges and numbers of cod used for tests are shown below:

	Fork Length (mm)				Weight (g)		
Test Series	n	$\bar{x}$	(range)	S.D.	$\bar{x}$	(range)	S.D.
Feeding Periodicity	78	99	(60-127)	13.6	7.7	(1.5-17.9)	2.9
Evacuation Rate	96	104	(89-139)	10.2	8.7	(4.8-20.3)	2.6

These lengths of fish correspond to arctic cod in age classes 1-2 (see 'Additional Life-history Data for Fishes').

Feeding Periodicity. Most feeding occurred during morning and early afternoon, tapering off by late afternoon and early evening (Fig. 30A). Stomach contents averaged 2.2% of the body weight of the fish at mid-morning (10:00-11:30 ADT), and increased to 4.8% of body weight by early afternoon (15:00). Thereafter, it appears that feeding diminished or ceased since stomach fullness steadily decreased until late evening or early morning. Some feeding resumed during early morning hours since stomach contents were not further depleted. This feeding pattern, particularly the decline in feeding at night, was somewhat unexpected since arctic cod are known to feed during the prolonged "nighttime" of the arctic winter except during spawning (Moskalenko 1964).

The observed diel pattern of stomach fullness appears to be a reasonable reflection of feeding behavior despite the complication that all data were not gathered during a single 24-h period (see 'METHODS'). The morning data gathered on the three dates (20, 21 and 24 August) did not differ significantly between each other (Paired Student's t Test, all $P > 0.01$), but the pooled morning data differed significantly from the 15:00 ADT data ($P < 0.05$). Therefore, these observations will be assumed to represent the diel feeding pattern of cod during their late-summer incursion into Simpson Lagoon.

Gastric Evacuation Rate. Freshly-caught arctic cod were held under field conditions (4.5-6.5°C, salinity 24-26 ppt) to monitor the depletion of natural foods (mysids, amphipods and copepods) from their stomachs. An approximate evacuation rate of 0.1% of total body weight/h was estimated from the data presented in Fig. 31A. However, this value is almost certainly an underestimate of the actual mean evacuation rate.

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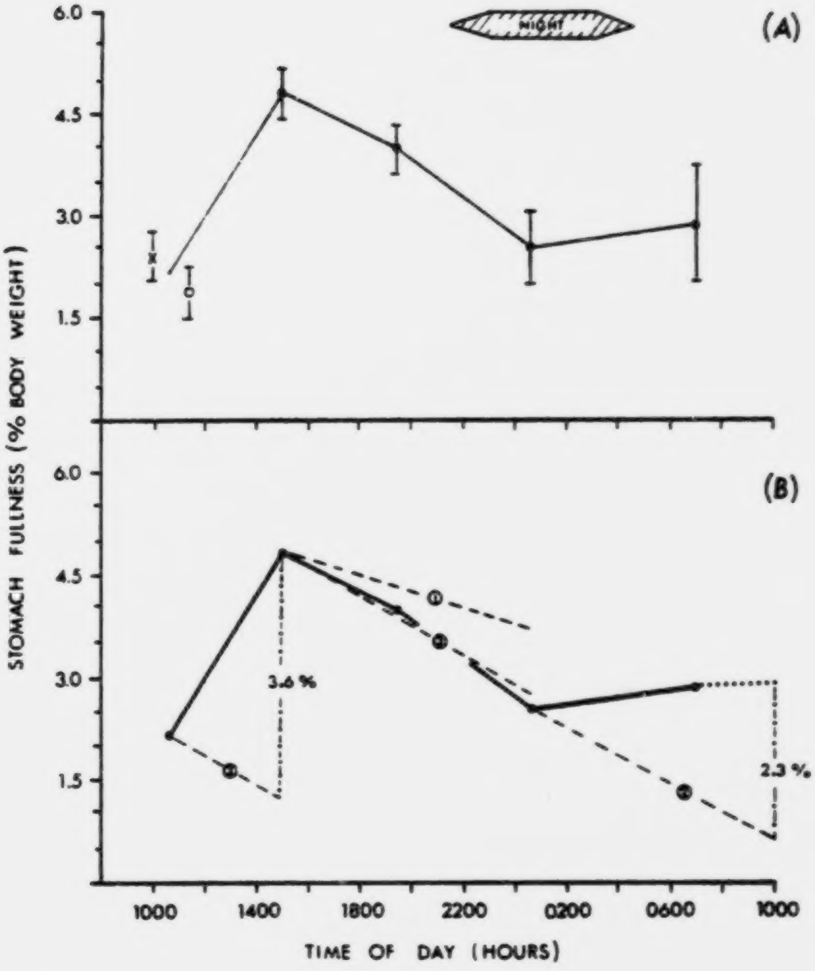

Figure 30. Feeding periodicity and daily ration of juvenile arctic cod in Simpson Lagoon. (A) Sample means (n = 10-20) and standard error bars are indicated for collections on 20 August 1978 (open circle), 21 August 1978 (x) and 23-24 August 1978 (closed circles). (B) Diagrammatic method used to calculate daily ration of arctic cod where two digestion rates (①,②) are indicated (see text for explanation).

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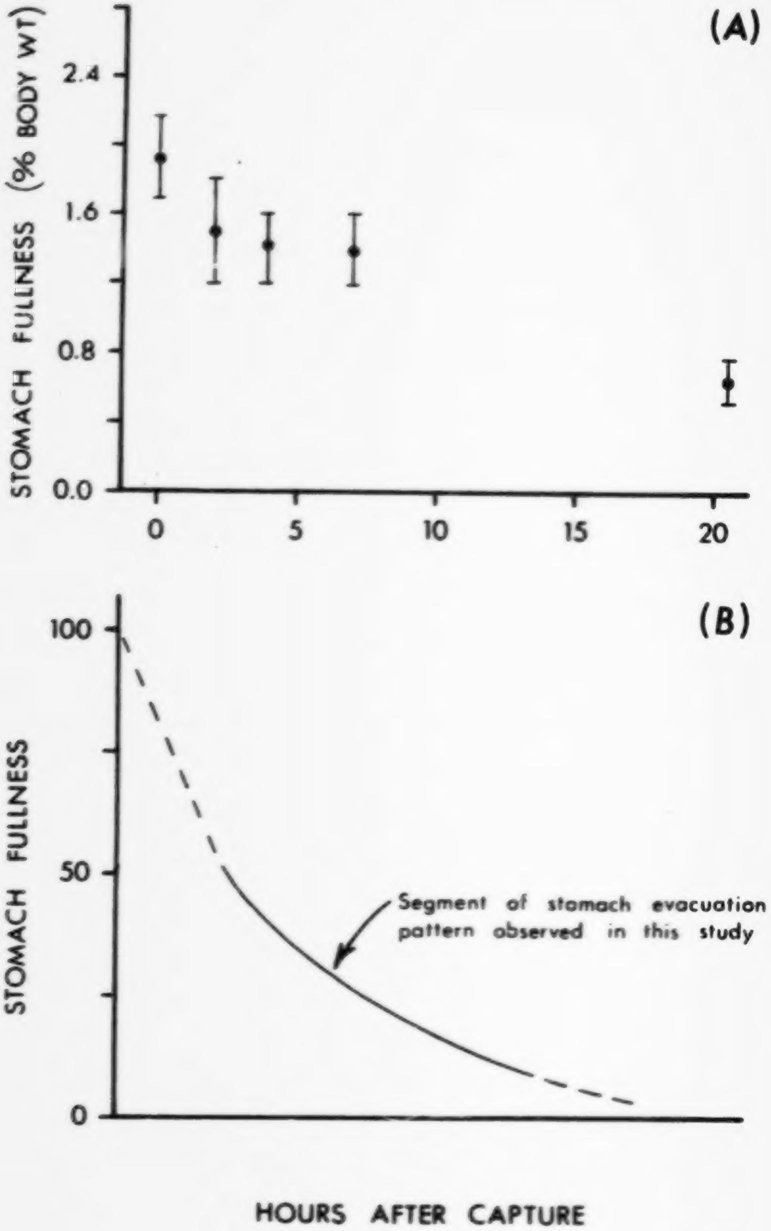

Figure 31. Evacuation of food from stomachs of juvenile arctic cod. (A) Means and standard errors for samples of fish (n = 18-20) held in a food-free pen in Simpson Lagoon, 20-21 August 1978. (B) Evacuation rate as a function of stomach fullness, based on results from other studies of other species (see text).

Although the experiment was conducted when cod stomachs appeared reasonably full, later laboratory measurements showed that stomach contents of these fish at the time they were captured averaged only 1.9% of body weight, a low value compared to the peak of 4.8% of body weight recorded at 15:00 during the feeding periodicity experiment (Fig. 30A). It appears, then, that due to the feeding periodicity of the fish, or other unknown factors, the evacuation experiment began when the cod stomachs were only half full. The significance of this point is that food does not pass through a fish's stomach at a constant rate--the rate varies according to the fullness of the stomach (e.g., Magnuson 1969; Tyler 1970; Windell et al. 1976). The rate is fastest when the stomach is full, slowing down as the stomach empties. Thus, most gastric evacuation occurs during the initial hours following a meal, and consequently, calculation of the evacuation rate with less than full stomachs, as occurred in the present study, underestimates the rate at which most evacuation actually occurs. This point is illustrated on a schematic diagram of an evacuation pattern observed in other fishes (Fig. 31B).

Evidence that the observed rate of 0.1% of body weight/h is unrealistically low is shown in Fig. 30B where this evacuation rate (indicated by the symbol 1 in Fig. 30B) is applied to the daily pattern of stomach fullness. It is apparent that, during the period 15:00-00:30 ADT, stomach contents were depleted at a rate that considerably exceeded the estimated evacuation rate.

A more realistic evacuation rate can be estimated in two ways:

1. Data from various studies (e.g., Tyler 1970; Windell et al. 1976) show that the rate of gastric evacuation is approximately twice as fast during the first half of the evacuation process (from full to half full stomach) than during the second half (half full to empty). Using this rough conversion factor, the initial evacuation rate for arctic cod then becomes 0.2% of body weight/h.
2. Data gathered to assess the feeding periodicity of arctic cod also provide a minimum estimate of the evacuation rate. During the period 15:00-00:30, the average stomach fullness declined almost 50% in a seemingly linear fashion (Fig. 30B). This decline, which is 0.2% of body weight/h, represents

> a minimum estimate of the evacuation rate because the actual rate must have been higher if the fish were feeding during this interval.

Both of these methods provide a similar estimate of evacuation rate, and this rate of 0.2% of body weight/h is used in subsequent calculations.

Calculation of Daily Ration. Calculation of the daily ration of arctic cod is based on the changing amount of food in their stomachs over a 24-h period and the rate of evacuation of this food from the stomach (Fig. 30B). As described below, the daily ration is calculated as the sum, over a 24-h period, of differences between the observed quantity of food in the stomachs versus the quantity that would have remained if the fish had digested what was present in the stomachs previously but eaten no additional food.

At the start of the feeding periodicity experiment, the stomach contents averaged 2.2% of the body weight of the fish (Fig. 30B). If no additional food had been ingested before the next sampling period, the stomach contents would have diminished at the rate of gastric evacuation, 0.2% body weight/h (indicated by symbol 2 in Fig. 30B), to approximately 1.2% body weight. Instead, the stomach fullness rose to 4.8% body weight, representing an actual increase of 3.6% body weight for this period. During the next two time periods, between 15:00 and 00:30 ADT, the decline in stomach fullness matches the estimated gastric evacuation rate--primarily because the evacuation rate was determined, in part, from these data and the assumption that no feeding occurred in this interval. The next major period of feeding occurred in the morning hours, sometime after 00:30. During this period, it is estimated that an additional 2.3% body weight was consumed (note that Fig. 30B is extrapolated to 10:00 on 24 August in order to complete a 24-h period). Summing these calculations, the amount of food eaten per day is 3.6% of body weight + 2.3% of body weight = about 6% of body weight.

In view of the assumptions and potential sources of error associated with each stage of the calculation of daily ration, it is clear that the value determined during this exercise is an approximation. On the other hand, this is the only known estimate for any species of fish in the

North American Arctic. Furthermore, these arctic cod data are particularly relevant since the experiments were conducted in field conditions using natural foods.

Daily rations of species like arctic cisco, arctic char and fourhorn sculpin are unknown, but estimates are necessary to compare the food requirements of consumers with available food supplies in Simpson Lagoon. It is therefore necessary to assign values for daily ration; the arctic cod data of 6% body weight will be used for all small fish (generally 100-250 mm in length). Large fish (generally 250-500 mm) and the relatively sedentary sculpins presumably require less food and so will arbitrarily be assigned 5% body wight/day as a daily ration.

Using these values for daily food requirements of fish and the estimated densities of large and small fish in Simpson Lagoon (see 'Estimated Densities of Combined Species'), Griffiths and Dillinger (1980) calculate that the available food supply (i.e., mysids and amphipods) in Simpson Lagoon was roughly 150-1,000 times greater than the total daily food requirements of fish in 1977 and 10-100 times greater in 1978. It appears, then, that there is an ample supply of mysids and amphipods for fish to eat.

Influence of Other Organisms

Three potential sources of mortality to fishes are examined: fishing pressure, predation and parasites. It appears that, with the possible exception of man, other organisms do not strongly influence population sizes of fishes in nearshore waters of the Beaufort Sea.

Human Use of Fish Resources

Anadromous fish, particularly cisco, whitefish and char, are the focal point of several fisheries along the Beaufort coastline in Alaska. Principal areas where fish are taken include (1) domestic fisheries near Barrow, the Colville Delta (Nuiqsut Village) and Barter Island (Kaktovik Village), (2) a commercial fishery in the Colville Delta (Helmericks) and (3) sport fishing at villages, DEW line stations and oil camps.

This information is of direct interest to the present study because all these fisheries catch at least some fish that pass through Simpson Lagoon during the open-water season. Tagging data from our study (Fig. 32) show that some fish passing through Simpson Lagoon are caught in nets from Barrow to Barter Island, a distance encompassing much of the Beaufort coastline in Alaska. Therefore, these fisheries must be viewed as sources of mortality to the study populations.

In the following sections, the commercial and domestic fisheries nearest the Simpson Lagoon study area are described. At this stage, however, it is not possible to determine the effects of human harvest rates on Simpson Lagoon fish populations because (1) fish population sizes are not known, (2) harvest rates are usually not well-documented and (3) proportions of "Simpson Lagoon fish" killed in the various fisheries are not known.

Commercial Fishery. The only continuing commercial fishery operating on Alaska's North Slope is located adjacent to the study area in the Colville Delta. It is operated by a single family (Helmericks) during the summer and fall months. Of these two fishing periods, the fall fishery accounts for the greatest amount of effort and yield.

Fall fishing takes place in the Kupigruak and East channels adjacent to Anachilik Island (Fig. 6) starting in the early part of October. When the ice becomes thick enough to walk on, holes are drilled and gill nets are set in a continuous series along the deep bottom of the channel. The nets are usually 2 m x 50 m and mesh size is 7.6 or 10.2 cm (stretched dimensions). The smaller mesh size is used in both channels, but the larger is used exclusively in the main channel where humpback whitefish occur more commonly. The total number of nets in each channel varies depending upon daily catch trends (i.e., nets are moved back and forth to where the fishing is best). Daily fish catches vary widely. The number of fish caught early in the season is low, steadily rising to a peak in early November. Thereafter, a steady decrease occurs until early December when the catch is again low and fishing is terminated.

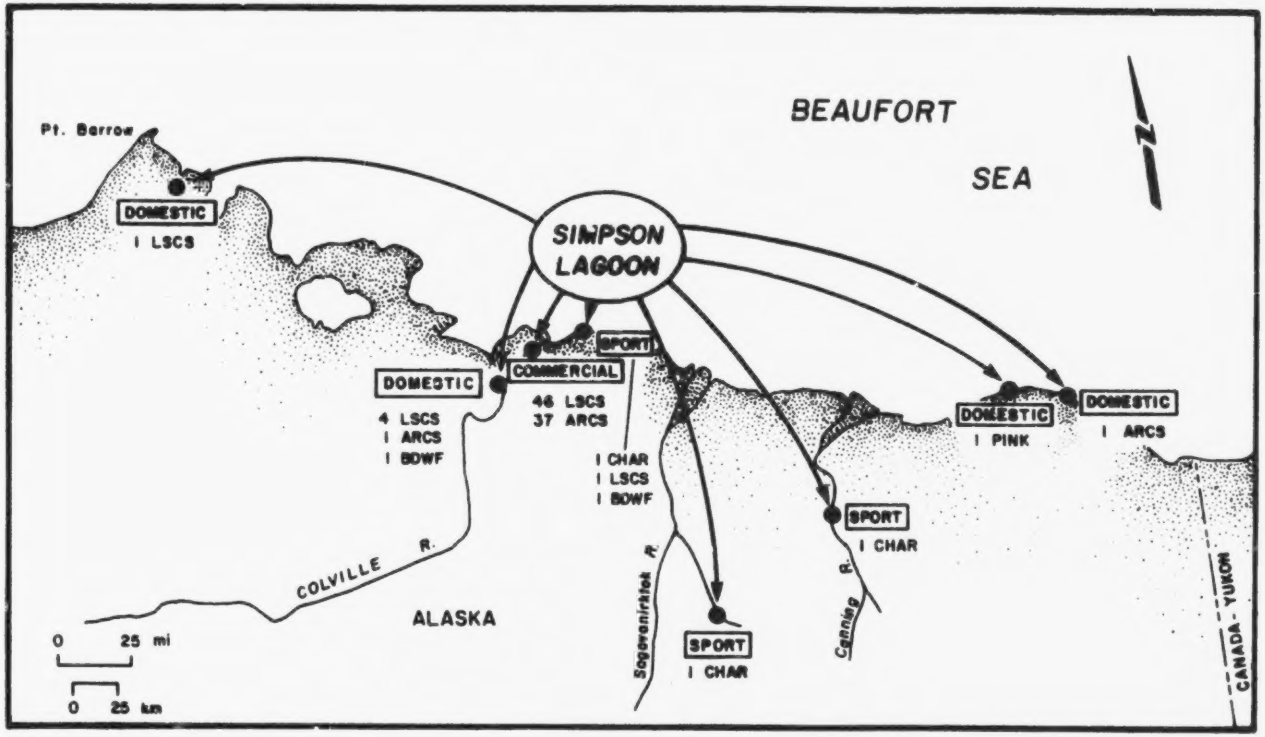
BEAUFORT
SEA
N
Pt. Barrow
DOMESTIC
1 LSCS
SIMPSON LAGOON
DOMESTIC
4 LSCS
1 ARCS
1 BDWF
SPORT
COMMERCIAL
46 LSCS
37 ARCS
1 CHAR
1 LSCS
1 BDWF
DOMESTIC
1 PINK
DOMESTIC
1 ARCS
SPORT
1 CHAR
SPORT
1 CHAR
COLVILLE R.
ALASKA
Sagavanirktok R.
Canning R.
CANADA - YUKON
0 25 mi
0 25 km

Figure 32. Fish tagged in Simpson Lagoon and recaptured in commercial, domestic or sport fisheries. Specific mark and recapture data are listed in Appendix 1. Abbreviations: ARCS (arctic cisco), LSCS (least cisco), CHAR (arctic char), BDWF (broad whitefish), PINK (pink salmon).

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Catch records (ADF&G 1977) show the annual harvest from 1964 to 1976 has been as follows:

	Average Catch			
Species	Number	%	Average Weight of Fish (lb)	Total Weight (lb)
arctic cisco	37,284	65	1.0*	37,284
least cisco	16,682	29	0.6*	10,009
broad whitefish	2,816	5	5.1**	14,362
humpback whitefish	701	1	5.1**	3,575
Total				65,230

* from subsample of commercial catch.

**ADF&G 1977.

These records exclude 1967 and 1969, when the commercial fishery did not operate.

Arctic cisco is the most important cash product in the fishery. This species, along with broad and humpback whitefish, is sold for human consumption in Fairbanks and Barrow. Numbers of arctic cisco harvested have varied greatly over the years (Fig. 33), with the lowest recorded harvest occurring in 1979. This apparent decline in numbers of arctic cisco, as well as implications of the age structure and maturity of the commercial sample, have been discussed in other sections of this report (see 'Population Numbers' and 'Additional Life-history Data for Fishes'). The average exploitation rate of arctic cisco in the commercial fishery is estimated at 9.2% (range 3.9-18.2%) based on preliminary mark-recapture estimates of "catchable" fish during the years 1976-1979 (Table 15).

Least cisco are also taken in large numbers (Fig. 33), but these fish are less desirable for human consumption because of their lean body. Most are sold for dog food and also for animals kept at the Naval Arctic Research Laboratory in Barrow. Descriptions of estimated numbers and life-history characteristics of commercially-caught least cisco are presented elsewhere (see 'Population Sizes and Additional Life-history Data for Fishes'). The average exploitation rate of least cisco in the commercial fishery is estimated at 5.1% (range 1.2-11.3%) based

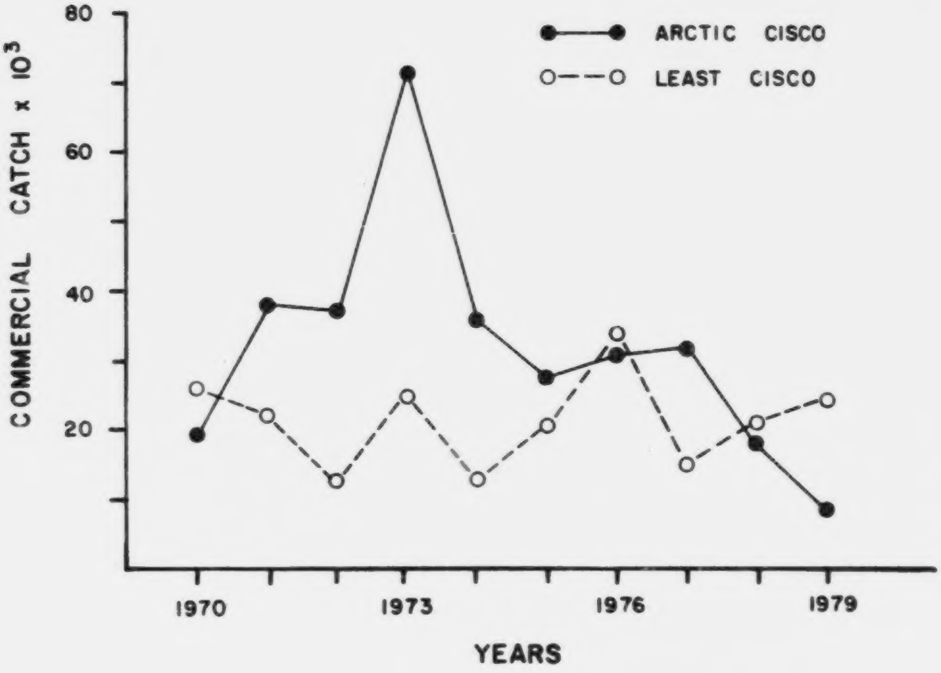

Figure 33. Commercial catches of arctic and least cisco in the Colville Delta, 1970-1979. Fishing effort was not necessarily equal each fall.

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on preliminary mark-recapture estimates of "catchable" fish during the period 1976-1979 (Table 15).

Domestic Fishery. The Colville Delta also receives fishing pressure from a domestic fishery at the village of Nuiqsut. Although the native population has been quite small until recently, summer fishing camps (e.g., Woods Camp on the Nechelik Channel) have been in operation for some time. For example, in 1951, 10,000 pounds of whitefish were transported from the Colville Delta for use in Barrow (Wilimovsky 1956). The recent establishment of Nuiqsut at the head of the delta in 1973 has created a local demand for fish.

In the same fashion as the Helmericks' commercial fishery, fishing for domestic use is largely within the Colville River and takes place in both summer and fall. Fish are caught primarily with gill nets, 3.1 to 12.7 cm mesh size (stretched), of variable panel lengths. Summer fishing takes place at a variety of places around the village including the Nechelik Channel and a deep pool at the confluence of the Itkillik and Colville Rivers. Fall fishing takes place in the lower parts of the delta channels where the catch of migrating ciscoes is comparatively greater. Some fall jigging for burbot also takes place in the previously mentioned deep pool.

Very little is known of the numbers of fish taken annually for domestic use at Nuiqsut, since subsistence fishermen are not required to report catch statistics. Two rough estimates (outlined below) suggest that the harvest is probably similar to that taken in the previously mentioned commercial fishery:

> Estimate #1. Wilimovsky (1956), speaking in general about fishing practices of North Slope inland fish camps, estimates that the summer catch is "in the neighborhood of 1500 pounds per fishing group (a family with sled and/or boat and two to five nets)"; fall or winter fishing catches per fishing group are somewhat greater. Using these figures, a conservative estimate of annual catch per fishing group may be 3500 pounds. The number of Nuiqsut families known to fish during the summer of 1978 was about 7 (Verstratt 1978 pers. comm.). This means that a very rough estimate of domestic catch by Nuiqsut is in the neighborhood of 24,500 pounds (7 groups x 3500 lbs/group).

> Two points of caution must be taken concerning this estimate. Many fishing groups may not fish if other sorts of occupation are available. This was the case in 1978 when the Nuiqsut High School was under construction, employing many people who would otherwise be fishing. Secondly, Colville fish may also be taken by subsistence fishermen from Barrow and other communities who come to the Colville to fish. Consequently, the number of fishing groups may be greater than that at Nuiqsut alone. Therefore, 24,500 lbs is considered an underestimate.
>
> Estimate #2. Another means of estimating Nuiqsut's annual fish harvest is by using data obtained at the village of Aklavik, another delta village (Mackenzie River) on the Beaufort Sea coast. Brakel (1977) determined that the average Aklavik family of six people, with 1.5 dogs, consumed 2,649 pounds of fish. Applying these figures to Nuiqsut, which has a population of 157 (Pederson 1979)--the equivalent of 26 six-member groups--the annual village requirement would be 68,874 pounds.

Predators

Predator pressure on fishes in the nearshore environment appears to be surprisingly low. Although beluga whales, seals, birds and some fish are all known to feed on Beaufort Sea fish, predators tend to be scarce in areas where anadromous fish are abundant. And, when predators are taken in lagoons and other nearshore areas, stomach analyses show they often feed on invertebrates in summer, although ringed seals eat some arctic cod in winter (Lowry et al. 1978). Most fish recorded in whale and seal stomachs are marine species rather than the anadromous species of nearshore habitats (e.g., Fraker et al. 1978; Lowry et al. 1978).

Few potential predators were sighted in the Simpson Lagoon study area during the 1977 open-water season. Johnson and Richardson (1980) report that a total of only 16 seals, mostly ringed seals, were sighted inside the lagoon during 21 aerial surveys flown during the summers of 1977-1979. During this same period, beluga whales were sighted twice in the ocean near Pingok Island, but none was seen in the lagoon itself. Fish-eating birds were not abundant; Johnson (pers. comm.) estimated the density of loons to be approximately 0.3-0.4 birds/km^2 in the whole lagoon system during three summers, 1977-1979. Even potential fish predators fed infrequently on small fish in Simpson Lagoon (see 'Feeding Ecology'). Only boreal smelt, which were locally abundant off the Colville River in winter, fed heavily on marine fish (arctic cod).

Parasites

A preliminary examination (see 'METHODS') of fish parasites was initiated during this study because parasite infections of coregonid fishes may cause deterioration in physical condition and reduce growth of fish (reviewed in Bauer 1970 and Lawler 1970), or affect the ability of fish to resist the environmental effects of chemical pollutants (Boyce and Yamada 1977; Perevozchenko and Davydov 1974 cited in Boyce and Yamada 1977). Therefore, arctic cisco, an ecologically and economically important fish species, was examined for potentially detrimental parasite species. Specific objectives were to (1) evaluate the significance of parasitism in the energy budget of the fish population, (2) determine if parasite infections caused deterioration in fish condition, (3) determine if there is any period when parasites are especially prevalent and could be a factor affecting the ability of the fish to withstand additional stress, and (4) determine if these economically important fish hosted any parasite species potentially dangerous to man or other mammals.

Results. No parasites were found on the gills. The viscera were infected with three types of parasites that occurred in sufficient numbers to be of interest in terms of study objectives: (1) an adult tapeworm (*Diplocotyle olrikii*), (2) a tapeworm intermediate stage (*Diphyllobothrium* sp.), and (3) an adult acanthocephalan (*Neoechinorhyncus tumidus*).

The adult tapeworm, *Diplocotyle olrikii*, occurred in the lumen of the pyloric caeca and intestine. Bauer (1970) reports that in Russia this species infects fish in marine waters but perishes when the host migrates into fresh water. The pattern of infection in the study population (Fig. 34) coincides with that observation. Fish collected in the brackish lagoon waters during mid- and late summer periods were highly infected (84-92%) in contrast to those fish that had returned in early

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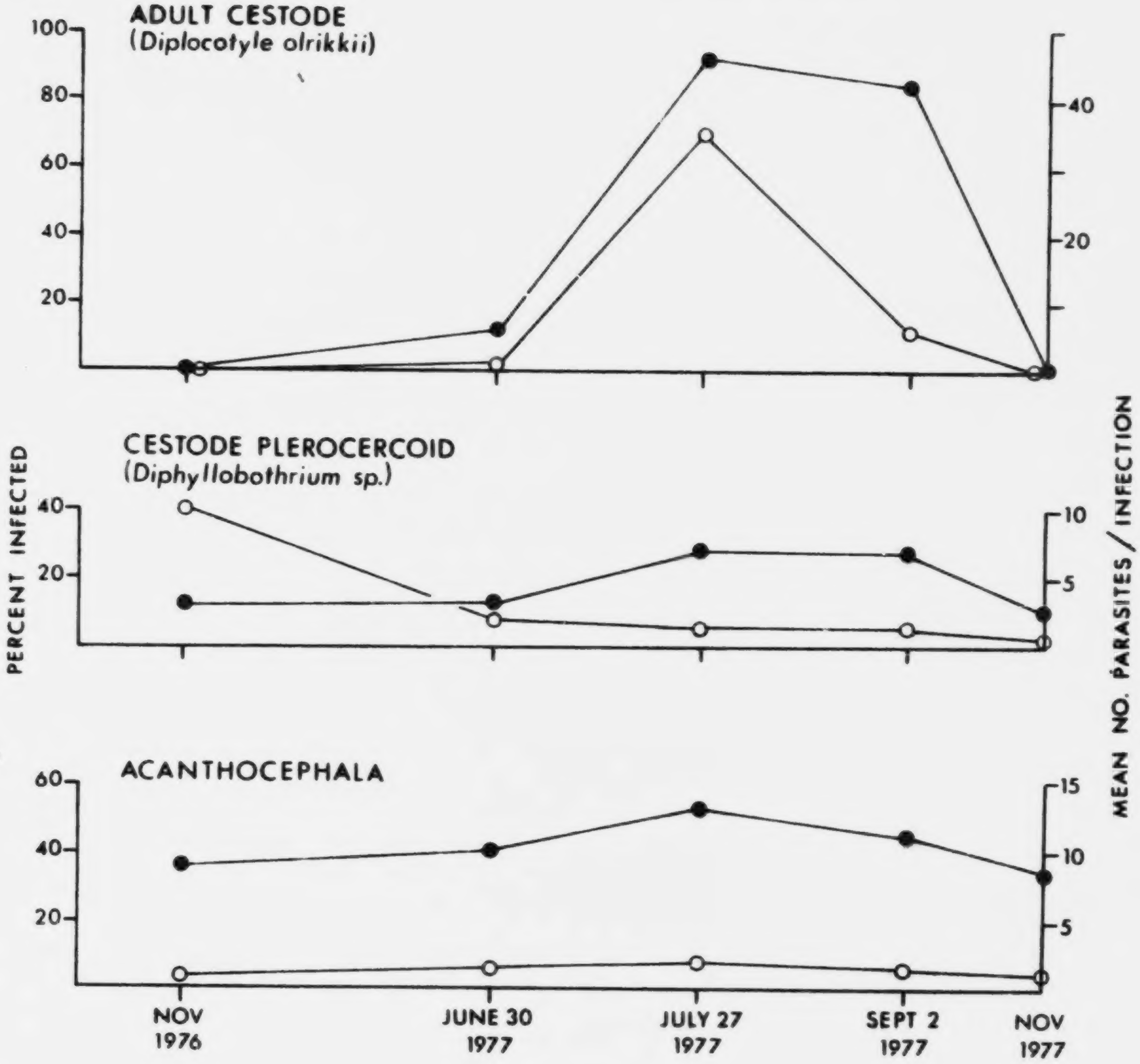

Figure 34. Intestinal parasites of arctic cisco from Simpson Lagoon and the Colville River Delta. Percent infection (solid dots) and mean number of parasites per infected fish (open dots) are indicated. On each date, 21-25 arctic cisco were examined.

winter to fresh water in the Colville Delta (0% infection). Average number of tapeworms per fish (35.6) was highest on 27 July. These were small tapeworms about 1 cm in length, which grew to 304 cm by 2 September, though they were few in number by that time (5.7 per infection). The absence of *D. olrikii* in November samples both in 1976 and 1977 indicate an annual cycle of infection. Lawler (1970) reports that *D. olrikii* may retard fish growth and cause general deterioration, but apparently this requires much higher infection levels than we found in this study.

A second tapeworm, *Diphyllobothrium* sp., occurred as a plerocercoid (first intermediate stage) on the stomach wall, pyloric caeca walls and mesenteric tissue. Most specimens measured 2-3 mm in diameter. This parasite probably matures in fish-eating birds, although there have been reports of *D. dendriticum*, a species infecting man, occurring in arctic cisco (Bauer 1970). It is possible, therefore, that this fish does harvest a harmful parasite, and eating the whole fish (including the stomach) could be dangerous. The infection level of this parasite does not appear high enough to adversely affect the fish (Fig. 34).

The acanthocephalan found in the intestine was identified as *Neoechinorhyncus tumios*. These adult parasites are "spiny-headed worms", 0.5-1 cm in length, which probably have a lagoon amphipod as their intermediate host. Acanthocephalan (*Echinorhynchus* spp.) infections have been reported to cause deterioration in coregonid fishes when infections of over 250 per fish occur; however, infections of 30 or less per fish have shown little effect (Bauer 1970). Consequently, it seems likely that infection levels in the Simpson Lagoon samples are too low to be harmful (Fig. 34).

In general, the infection levels of all parasites in arctic cisco from Simpson Lagoon are low and do not appear to detrimentally affect the health of the fish. There was no significant correlation between the condition factor of a fish and its total intestinal parasite load at these levels of infection ($r = 0.06$, $P > 0.1$, $n = 25$) during September, when parasite infections were maximum for the season.

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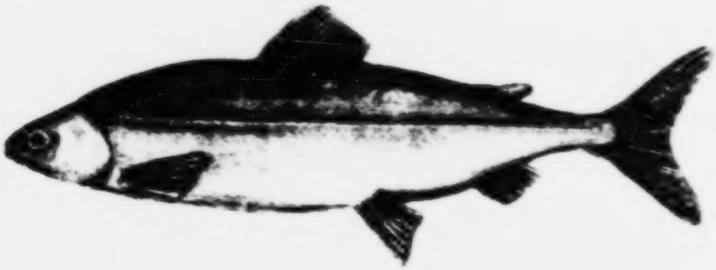
Conclusions. On the basis of this survey three species of intestinal parasites, two cestodes and an acanthocephalan, occur frequently enough to warrant evaluation in this study. Apparently none of these three occur at sufficient infection intensities to either affect the energy budget or decrease the condition or growth of the arctic cisco. Pending positive identification, the plerocercoid-stage cestode must be regarded as potentially dangerous to man or other mammals, such as dogs, that may eat the viscera. There is a marked seasonality in infection levels of the cestode *D. olrikii*, with maximum infection levels from about mid-July until the fish enters fresh water. If parasite infections do increase the susceptibility of arctic cisco to other stresses, such as chemical pollutants, the population would be most vulnerable during this mid-July period.

Additional Life-history Data for Fishes

Since the nature of our program has been to examine fishes from a community and ecosystem viewpoint, much of the information about particular species gathered during the study has been presented in previous sections on fish distribution, movements, population sizes, feeding ecology, predation and parasites. Additional life-history data concerning individual species are presented in this section. Age, length and maturity are principal topics but other types of new information are also presented.

Arctic Cisco



By several standards, the anadromous arctic cisco, *Coregonus autumnalis*, ranks as an important species in Alaska arctic waters. It is one of the most abundant and widely distributed fishes along the Beaufort Sea coastline, and it plays an important role in domestic fisheries from Barrow to Barter Island. Alaska's only North Slope commercial fishery, which is located in the Colville Delta, also focuses on this species--arctic cisco account for 41-72% of the annual catch (Alaska Dept. Fish and Game 1977).

Available information on the biology of arctic cisco has been obtained largely as a result of coastal studies of the anadromous segment of the population. In addition to the present study, Bendock (1977) describes arctic cisco in Prudhoe Bay, and Craig and McCart (1976) summarize earlier studies. Minimal data exist for the freshwater segment of this species, a point which is emphasized in this account because our understanding of the biology of this species remains very speculative in some respects.

Freshwater Sources of Arctic Cisco. Two large rivers, the Mackenzie and Colville, are considered to be the major sources of arctic cisco that enter coastal waters of the Beaufort Sea. Other Alaskan North Slope rivers may support this species but available data are incomplete.

Arctic cisco are reportedly taken in subsistence fisheries in several rivers near Barrow (T. Bendock, ADF&G, pers. comm.; F. Hobson, North Slope Bureau, pers. comm.). However, this species was not caught during a recent survey of streams in the Barrow area (Hablett 1980) although Hablett (pers. comm.) cautions that there may have been confusion in the identification of cisco species during this particular survey. Another complicating factor is that the coastal region at Barrow represents the area of distributional overlap for the arctic cisco and its look-alike, the Bering cisco (McPhail 1966; see discussion under 'Bering Cisco'). McPhail (1966; his Fig. 3) analyzed a sample of about 43 ciscoes from Elson Lagoon and found that only 30% were actually arctic cisco; the rest were Bering cisco. Thus, it would be necessary to confirm taxonomically which species is actually present in rivers like the Meade, Anaru and Chipp.

Alaskan streams to the east of the Colville have received more survey efforts but no river was found to support arctic cisco (e.g., Yoshihara 1973; Ward and Craig 1974; Craig 1976). Yoshihara (1973) reports that several arctic cisco were caught in the Sagavanirktok River but this drainage has been surveyed extensively in recent years and few, if any, other arctic cisco have been reported.

The Colville River lies adjacent to the study area, and tagging studies indicate that most, if not all, of the arctic cisco utilizing the Simpson Lagoon study area probably originate from this drainage. Of the 832 arctic cisco tagged in Simpson Lagoon, 41 were recaptured in the commercial fishery in the Colville Delta and only 2 were recaptured elsewhere (Appendix 1). Similar results were obtained for this species in Prudhoe Bay (Bendock 1977); of the 628 arctic cisco tagged there, 19 were recaptured in the Colville fishery and only 2 were recaptured elsewhere. However, as previously described in 'Fish Movements' it is understandable that most fish were recaptured in the Colville since recapture efforts were most intense at this site.

Very little is known about the freshwater phase of this important species. Even in the Colville River, the presumed source of many arctic cisco in Alaska, data are sparse. Appendix 2 describes our efforts to locate the spawning grounds of arctic cisco in the lower Colville drainage.

Size Distribution. Arctic cisco in Simpson Lagoon ranged in size from very small to very large fish (54-419 mm) but the size distributions of fish which were obtained depended on the sampling gear used. Fyke nets caught mostly small arctic cisco 60-200 mm long, and gill nets caught larger fish 280-400 mm long (Fig. 35). The former size group corresponds to juveniles ages 0-3 and the latter to older juveniles and mature fish ages 5-10 (Table 26). While sampling bias associated with these two capture methods may contribute to the apparent scarcity of the fish in the intermediate size ranges, the complete absence of age 4 fish in the 1977 sample (Fig. 36) suggests that the bimodality in size may also be a consequence of a poor 1973 year-class. Ages of the 1978 samples were not determined, but the size gap appears to be at a length

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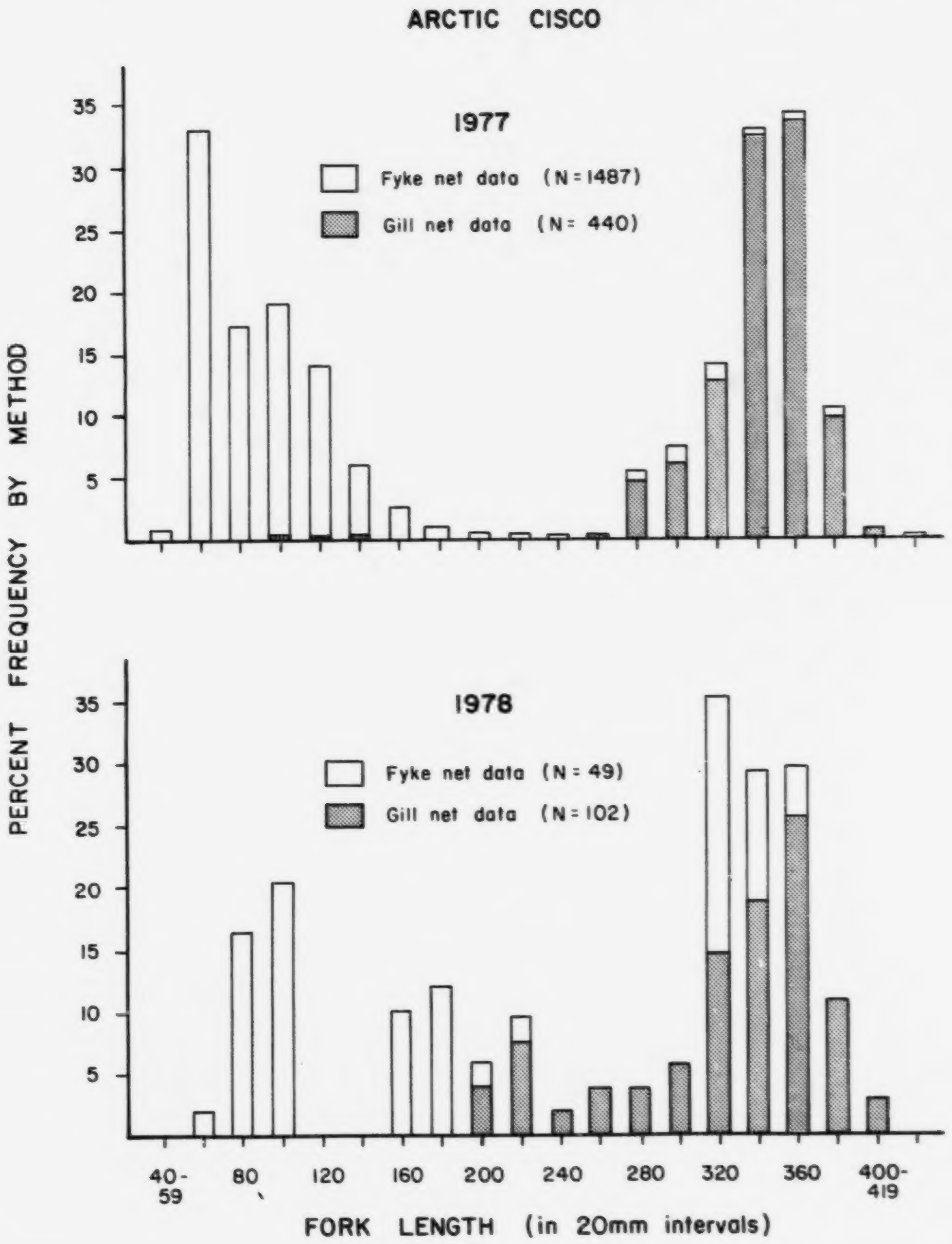

Figure 35. Length frequencies of arctic cisco caught in Simpson Lagoon, 1977-1978.

Table 26. Age-length relationship (derived from otoliths) and age-specific maturity of arctic cisco in Simpson Lagoon, 1977. Immature fish (I) and mature fish that would (S) or would not (NS) spawn in the year of capture are indicated.

					Maturity							
	Fork Length (mm)				Males				Females			
Age	n	mean	(range)	SD	n	% I	% S	% NS	n	% I	% S	% NS
0	18	73	(54- 96)	11	-	-	-	-	-	-	-	-
1	40	112	(65-145)	15	23	100	0	0	7	100	0	0
2	15	155	(129-188)	22	7	100	0	0	6	100	0	0
3	9	175	(151-227)	23	7	100	0	0	2	100	0	0
4	0	-	-	-	0	-	-	-	0	-	-	-
5	14	293	(261-318)	15	5	100	0	0	6	100	0	0
6	24	310	(290-340)	16	7	100	0	0	17	100	0	0
7	13	348	(330-398)	20	7	57	43	0	7	100	0	0
8	63	352	(292-394)	21	36	47	53	0	27	73	19	8
9	121	364	(333-400)	16	63	6	71	22	54	22	24	54
10	35	368	(349-390)	10	17	0	58	42	17	0	65	35
11	0	-	-	-	0	-	-	-	0	-	-	-
12	0	-	-	-	0	-	-	-	0	-	-	-
13	0	-	-	-	0	-	-	-	0	-	-	-
14	1	410	-	-	1	0	100	0	0	-	-	-
Overall	352				173	43%	45%	12%	143	54%	20%	26%

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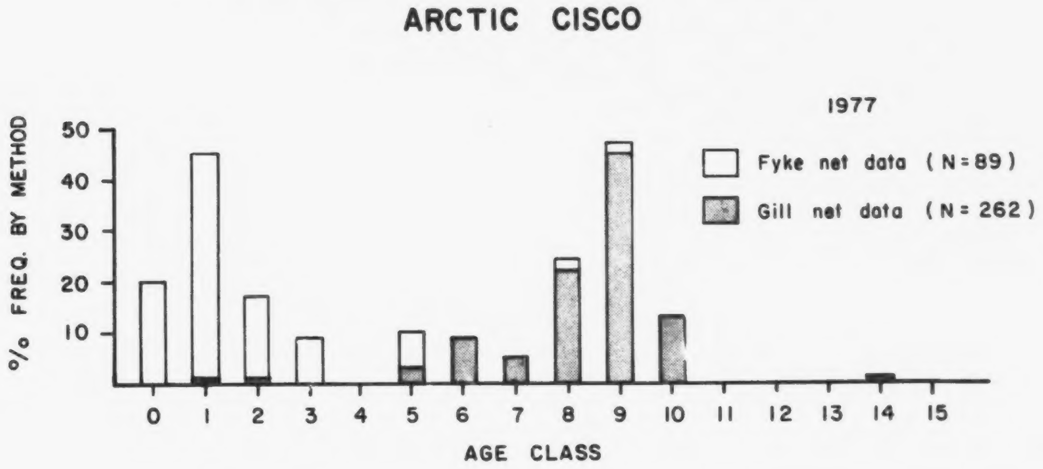

Figure 36. Age frequency of arctic cisco in Simpson Lagoon, 1977. Open and shaded bars each total 100%.

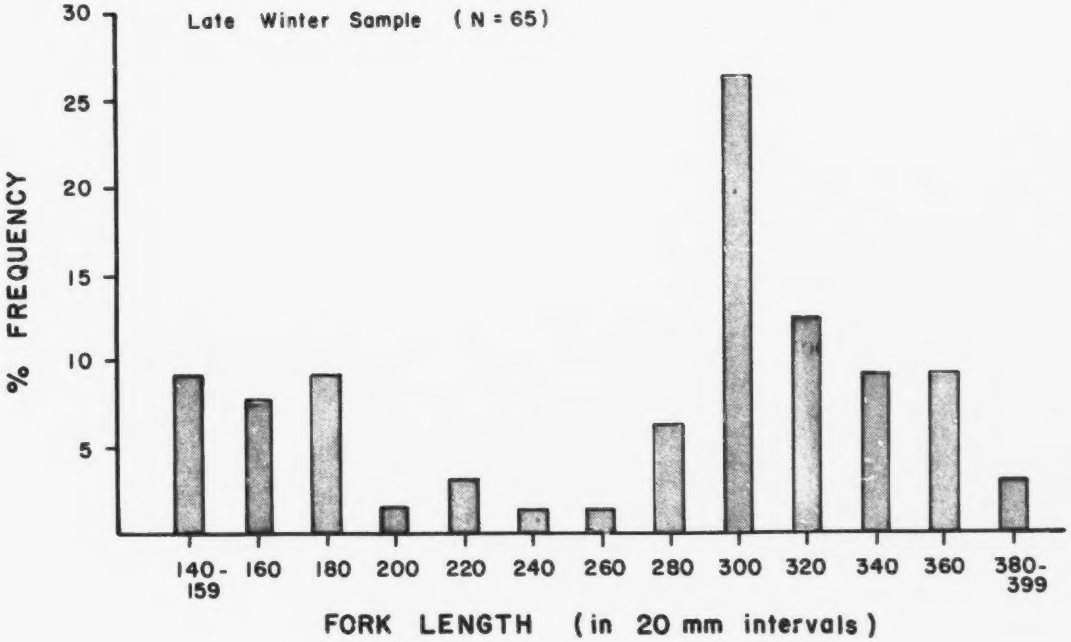

Figure 37. Length frequency of arctic cisco caught in late winter in the Colville Delta, 8 April-22 May 1978.

which would generally correspond to age 5 fish, thus supporting the likelihood of a poor 1973 year-class.

A comparison of the 1977 and 1978 size distributions also shows that small fish, 60-79 mm in length, corresponding to age 0 fish (fry), were much less abundant the second summer. Reasons for this or the lack of fish in the 120-159 mm size categories are not known. The fact that more large fish were caught by fyke net in 1978 than 1977 may reflect the larger fyke net used the second year (see 'METHODS').

Fyke net data from this study and Bendock's (1977) study at Prudhoe Bay show that small arctic cisco are more common in nearshore Beaufort Sea waters than indicated by earlier studies that relied on data obtained by gill nets. Figure 35 clearly indicates that variable-mesh gill nets underestimate numbers of small arctic cisco, even when some gill net panels have mesh sizes as small as 1.25 cm (0.5 inch bar mesh).

In late winter, medium and large size arctic cisco were caught in the lower Colville Delta. Under-ice gill nets caught fish 148-398 mm in length (Fig. 37), but it is clear from the foregoing that smaller fish, if present, would not have been caught by the gear used.

Age at First Seaward Migration. Arctic cisco smolt at an early age. In 1977, some entered the brackish waters of Simpson Lagoon as young-of-the-year, and age 1 fish were the most abundant age class of all arctic cisco caught by fyke net. Bendock (1977) reports that age 1 arctic cisco were also present in Prudhoe Bay, thus indicating that some small arctic cisco disperse at least 70 km from the Colville River. The proportion of juveniles that smolt at these early ages is not known.

Age, Growth and Maturity. Ages of arctic cisco in Simpson Lagoon cover the known age range for the Colville population; ages of the subsample of fish ranged from 0-14, with a distinctly bimodal distribution (Fig. 36). Growth of the Simpson Lagoon fish (Table 26) is generally similar to that of other populations of this species along the Beaufort Sea coastline (cf. Craig and McCart 1976). For the 1977 study population, two growth phases are apparent; (1) rapid growth for immature fish of ages 0-6, and (2) markedly slower growth as fish attain sexual maturity (Fig. 38).

Several differences were noted in the reproductive status of male and female arctic ciscoes in Simpson Lagoon. Males tend to reach maturity one year earlier than females. Most males mature at ages 7-9, females at ages 8-10 (Table 26). It should be noted that the spawning cycle of this species is not clearly understood, and accordingly, assessments of reproductive status are somewhat subjective (Craig and Mann 1974). The problem is basically as follows. Fisheries biologists catch many large and relatively old arctic cisco in coastal waters. Gonads in these fish exhibit an intermediate degree of development which distinguishes them from both immature fish and mature fish in a spawning condition. Researchers have been generally uncertain whether these fish represented (1) immature fish which, perhaps, would spawn in a year or so, (2) mature fish whose gonads would quickly increase in size in time for fall spawning, or (3) mature fish which spawned previously but would not spawn in that particular year (Nikolskii [1961] reports that this species does not spawn annually in Siberia). Various terms have been used to describe these fish and their state of maturity--some-development, potential spawner, non-spawner and mature non-spawner (Roguski and Komarek 1972; Kogl and Schell 1974; Craig and Mann 1974; Griffiths et al. 1975, 1977).

In fact, we do not know whether arctic cisco in the study area spawn more than once during their lifetime, and, if so, whether they spawn annually, in alternate years, or some combination of both. Spawning populations have yet to be located for this species and virtually no spawned-out fish have been caught. Therefore, it has been necessary to examine seasonal patterns in gonad development in order to assess the field biologists' assessments of maturity. Three categories have been used to describe the reproductive condition of arctic cisco in the study area (after Craig and Mann 1974): "immature" (negligible gonad development and no evidence of a previous spawning), "mature green" (sufficient gonadal development to indicate that the fish would spawn during the year of capture), and "mature non-spawner" (some gonadal

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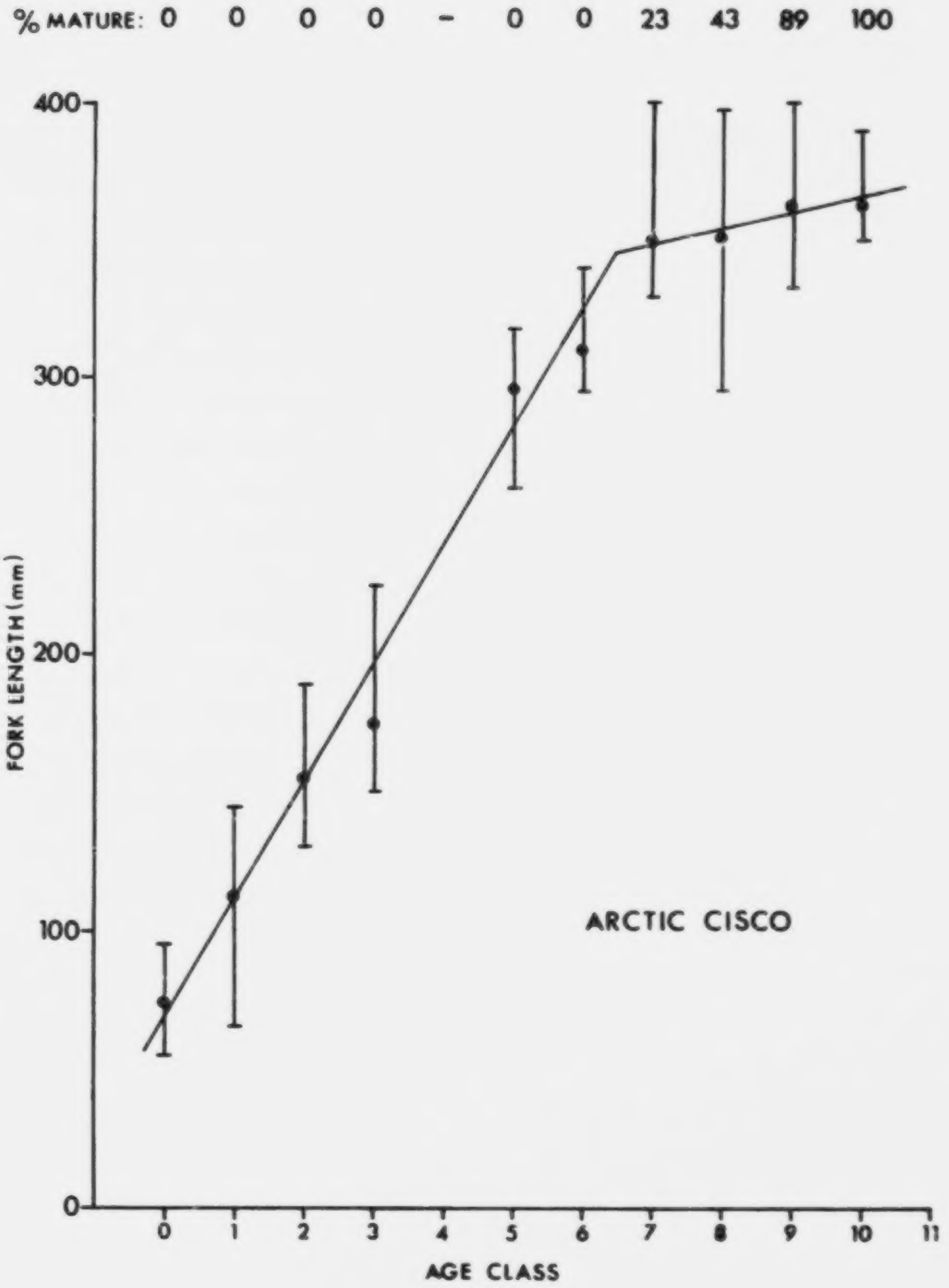

Figure 38. Growth of arctic cisco caught in Simpson Lagoon, 1977. Mean, range and percent mature (sexes combined) are indicated for each age class.

development but would not spawn during the year of capture). We emphasize that no direct evidence of a previous spawning was found in the coastal fish classified as mature non-spawners. Dissection procedures included a search for retained eggs, but none was found. In general, Craig and Mann (1974) found that there was some difficulty in distinguishing (1) large immatures from small mature non-spawners, and (2) mature green fish from mature non-spawners, early in the season when gonadal development was similar.

Seasonal patterns of egg sizes and testes:body weight ratios indicate that there is considerable overlap in reproductive conditions of fish judged to be immature, mature spawners and mature non-spawners (Fig. 39). The males with the most developed testes, in terms of gonad: body weight ratio (0.3-1.2%), were caught at the beginning of the open-water season. Some females with relatively large eggs (0.7-1.2 mm) were also taken at this time. Sizes of eggs at spawning time are not known for North American populations of arctic cisco; perhaps egg sizes are similar to those of least cisco (1.4-1.9 mm, Mann 1974) but Berg (1957) reports that eggs of spawning arctic cisco in Siberia are 2.5 mm. It is possible that females with the larger egg sizes in Simpson Lagoon would spawn later that year. A similar pattern of egg sizes was recorded for arctic cisco caught at Barter Island (Griffiths et al. 1977).

It appears, then, that spawners are present in early summer, presumably returning to the Colville or other spawning streams by early July. Juveniles and mature non-spawners remain in coastal waters for a longer time.

Movements in Fresh Water. To provide a more complete picture of the life cycle of arctic cisco, a brief summary of their movements after leaving coastal waters is presented. Data are fragmentary and our understanding is speculative:

1. Spawners. Previous studies documented no summer or early fall spawning runs up the Colville and so it was suggested that "spawners enter the Colville Delta late in the summer and spawn in the lower reaches of the river" (Kogl 1972). However, the data presented above suggest that most spawners return to fresh water, presumably the Colville, by early July. We do not know

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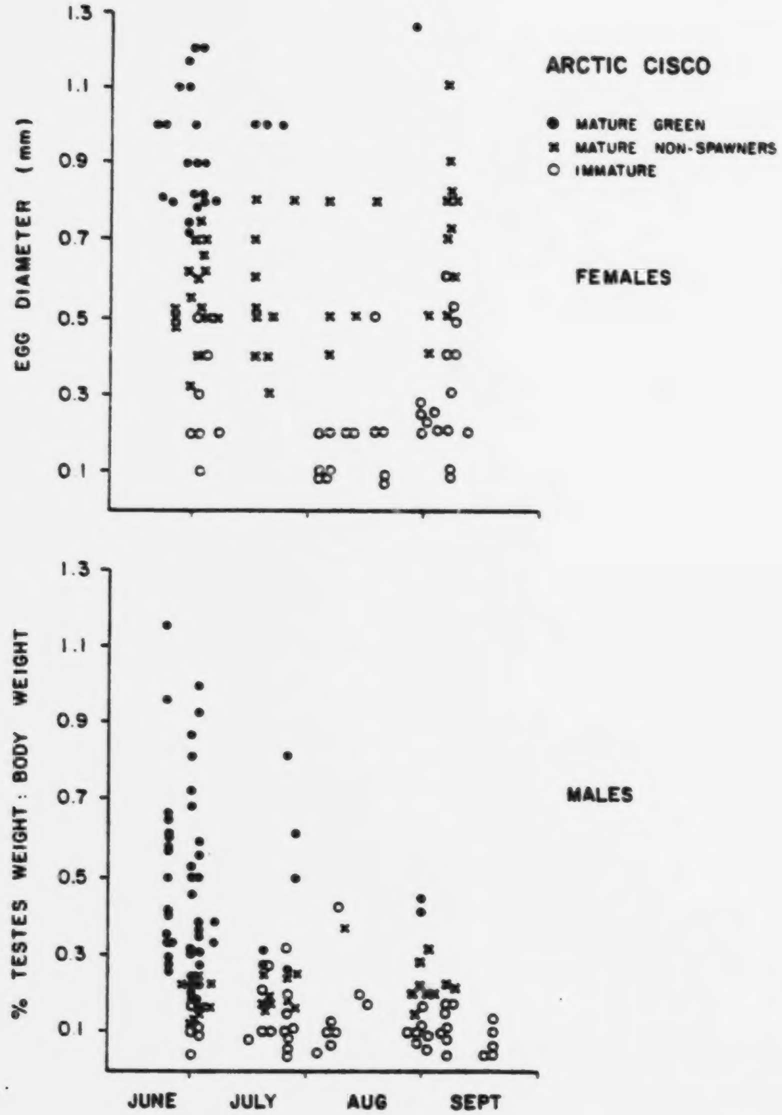

Figure 39. Seasonal patterns of egg sizes and testes:body ratios for arctic cisco in Simpson Lagoon, 1977. Only males > 200 mm long were used in this analysis since smaller immature males occasionally give erratically high values.

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where, specifically, these fish spawn; spawning arctic cisco have yet to be caught in any Alaskan waters (reviewed in Appendix 2). No post-spawning downstream run has been recorded either, although, of the hundreds of arctic ciscoes caught in the delta in winter, five apparently spawned-out individuals have been caught (3 in this study; 2 by Kogl and Schell 1974).

2. Sea-run Immatures and Mature Non-Spawners. The evidence indicates these fish move between the Colville Delta in winter and coastal waters in summer.
3. Young Juveniles. Presumably the movements of these fish are similar to those described in (2) above, but at least some spend the summer in the Colville as well (Kogl 1972). These small fish have not been caught in winter (Fig. 37), probably because they are not vulnerable to capture by gill net.

Length-Weight. The following length-weight relationship was obtained for combined coastal collections of arctic cisco:

$$\log \text{Weight (g)} = -5.617 + 3.279 \log \text{Length (mm)}, n = 785, r = 0.99^*$$

Sex Ratio. Male and female arctic cisco were present in almost equal numbers in the 1977 Simpson Lagoon sample ($n = 529$, 51.2% male, $\chi^2 = 0.32$, $P > 0.5$). Unlike other species (particularly arctic char), female arctic cisco do not have a greater tendency than males to become anadromous.

Overwintering Areas. A common belief among fisheries biologists is that anadromous fish overwinter in fresh water during the prolonged arctic winter and feed very little during this time because of lowered metabolic needs and scarcity of prey. Thus, fish would tend to be in their poorest physical condition after surviving the winter and best condition after summer feeding in coastal waters. It was surprising, therefore, that arctic cisco caught during the 1977 spring breakup in Simpson Lagoon were not thin, but healthy-looking, robust fish. As early as 30 June-2 July (two weeks before Simpson Lagoon was free of all ice), the fish had an abundance of fat along the intestinal tracts. Intestinal fat accounted for an average of 1.7% of the total body weight at this time; and this early season value was already one-half the total amount present by the end of the open-water season:

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*Common (base 10) logarithms used here and elsewhere in this report.

		Intestinal Fat (%)	Fork Length (mm)		Weight (g)	
Date	n	Mean (Range)	Mean (Range)	S.D.	Mean (Range)	S.D.
30 June- 2 July	18	1.7 (0.9-3.4)	360 (339-383)	14	577 (463-723)	66
7 Sept	15	3.6 (1.8-5.5)	369 (331-395)	17	664 (464-848)	103

Thus, these fish had either survived the winter with more than adequate food reserves, or had already had the opportunity to fatten up in the spring before entering the lagoon.

Two additional pieces of evidence, besides the foregoing results, suggested that arctic cisco may overwinter in nearshore or delta waters rather than, or in addition to, freshwater: (1) Helmerick's commercial fishery catches arctic cisco under the ice in the brackish waters of the Colville Delta until mid-December when fishing ceases, and (2) invertebrates ("shrimp") were active and abundant throughout the 1976-1977 winter in a hole through the ice opened by crews on an exploratory drill rig just off the Colville Delta. It appeared, on the basis of data available in 1977, that arctic cisco are present in the delta well into winter and that food (probably mysids and amphipods) is available at this time and in this area.

During the following two winters (1977-78, 1978-79) we found that arctic cisco do indeed overwinter in the brackish waters (18-32‰)of the Colville Delta although none was caught in coastal waters (see 'Winter Distribution'). During 8-20 April 1978, 67 arctic cisco (45% of the total catch) were caught under the ice in the lower Colville Delta near Anachilik Island (Fig. 6). These fish ranged from 148-398 mm in length (Fig. 37), 2-10 years in age (Table 27), and almost all were judged to be immature fish:

	Number of Fish		
	Immature	Mature Non-spawner	Mature Green
males	37	0	0
females	26	0	2?
unidentified	2	0	0

Table 27. Age composition of winter-caught arctic cisco in the Colville Delta.

	Late Winter Survey	Fall Commercial Catch (Helmericks)		
Age	April/May 1978	1976	1977	1978
2	15.2%	0%	0%	0%
3	6.1	0*	0	1.4
4	7.6	0	0.5*	10.7
5	3.0	3.2	57.7	10.2*
6	45.4	54.8	15.4	74.0
7	7.6	6.4	23.6	0.9
8	12.1	29.0	1.6	2.8
9	1.5	6.4	0.5	0
10	1.5	0	0.5	0
n	66	31	182	215

*The 1973 year-class--an apparently poor year for this species (Fig. 36).

Gonads of these fish were not very developed. For males, the average testes:body weight percentage was only 0.06% (n = 21, range 0.02-0.2% for fish > 200 mm long), and for females egg sizes were 0.2 mm or less except in two females (mature green) with 0.4 and 0.5 mm eggs. These indices of sexual maturity are far lower than those of mature spawners in June (Fig. 39), and so it is thought that most would not spawn in the year of capture (1978).

In summary, many arctic cisco (and least cisco) do not require freshwater habitats for overwintering. A large non-spawning segment of the population overwinters in the brackish waters of the Colville Delta, and during this time they continue to feed on invertebrates (see below). To date, no ciscoes have been caught in coastal waters in winter except in Siberia (Berg 1957) and in the nearly fresh waters off the Mackenzie Delta. Galbraith and Hunter (1979) report catching four arctic ciscoes in Kugmallit Bay, N.W.T. (12 December 1974); Percy (1975) caught a single arctic cisco in Mallik Bay, N.W.T., in slightly brackish waters (4.9-7.9%), on 10 March 1975; and Kendel et al. (1975) caught three arctic cisco in Mackenzie Bay in April 1974. Together, these data indicate tolerance of a wide range of salinities (4.9-32%) by overwintering arctic cisco.

The Commercial Fishery in the Colville Delta. For comparative purposes, samples of fish were purchased each year (1976-1979) from Helmericks' commercial fishery in the Colville Delta. These samples consisted of arctic cisco caught in autumn (October-December) under the ice in brackish delta waters. Subsamples were analyzed for age (n = 428), reproductive status (n = 689) and stomach fullness (n = 289).

Most fish caught in the commercial fishery are moderately large fish, 260-380 mm in length (Fig. 40). Reasons for year-to-year variability in sizes of fish in these harvests are not known, but may include differences in sampling dates, locations or gear (i.e., the proportions of 3 and 4 inch mesh gill nets used each year). The large mesh sizes probably account for the absence of small arctic cisco from the catch; fish smaller than those caught in the commercial fishery are present in the Colville Delta, at least during late winter (Fig. 37).

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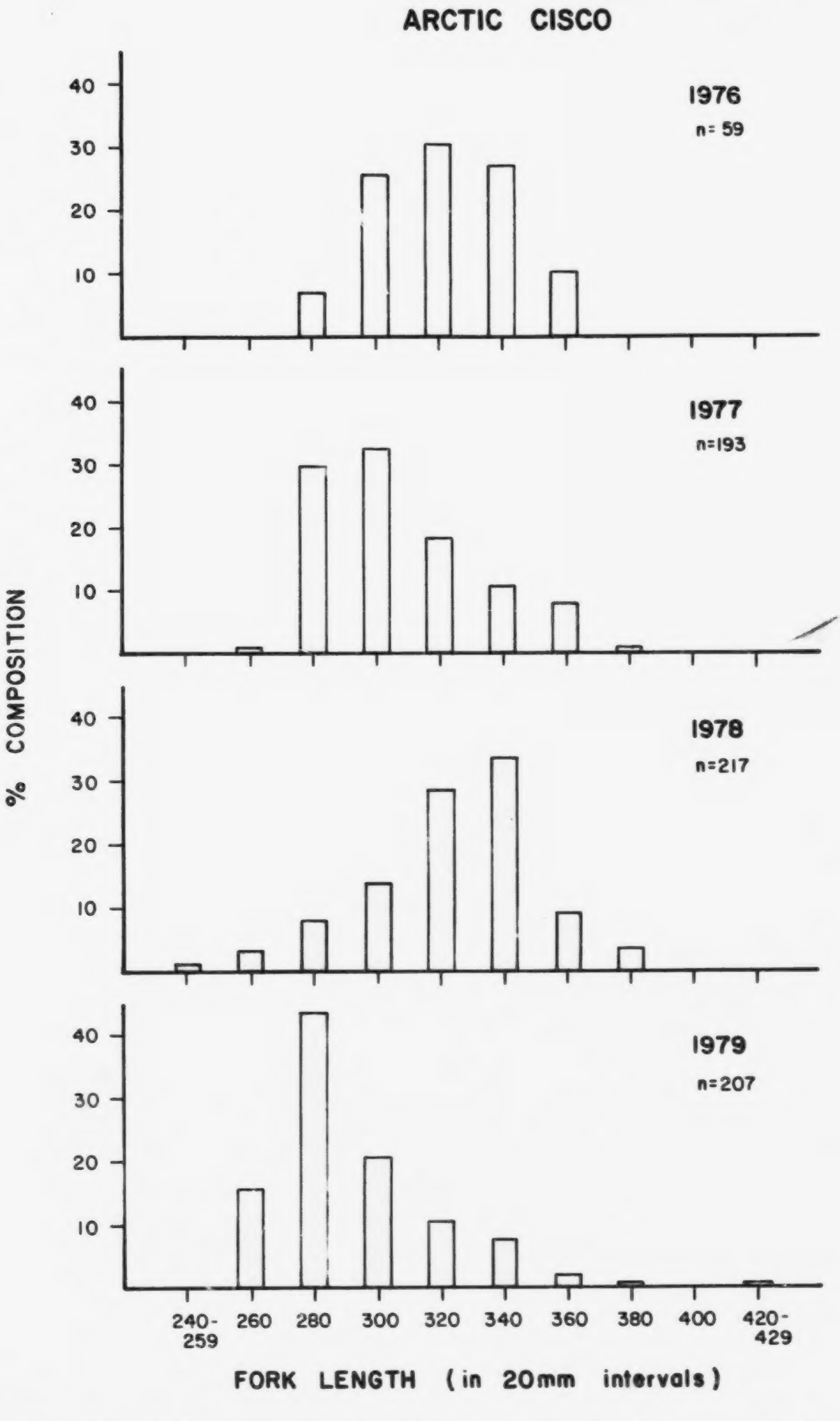

Figure 40. Length frequencies of samples of arctic cisco caught in the commercial fishery in the Colville Delta, 1976-1979.

The commercial catch ranged from 3 to 10 years in age with ages 5 to 8 comprising the bulk of the catch (Table 27). Some of the annual variation in the dominant age classes caught probably reflects the previously described poor year class of 1973 as it increased in age (size) and became vulnerable to the fishery. The recent decline in numbers of arctic cisco caught in the fishery (see 'Population Numbers') began prior to the entry of the 1973 year-class into the fishery, but the lack of fish in this year-class certainly contributes to the reduced catches.

Fish taken by the commercial fishery were judged to be immature fish or mature non-spawners:

		% Composition		
Year	n	Immature	Mature Non-spawner	Mature Green
1976	59	88	12	0
1977	196	43	57	0
1978	227	51	49	0
1979	207	45	54	0.5

Only a single male out of 689 commercially-caught fish was considered a possible mature green fish which might spawn in the year of capture. As in the arctic cisco caught during late winter in the delta (see previous section), gonads of these fish were not well-developed at the time of year when the species presumably spawn: in males the average testes: body weight ratio was only 0.07% (n = 16, range = 0.04-0.14%), and egg diameters of females were only 0.2-0.5 mm (n = 11) in immature females and 0.5-0.8 mm (n = 9) in mature non-spawners. These indices of sexual maturity are much lower than those of mature green fish in June (Fig. 39). No mature spawners or spawned-out fish were present in our samples; however, one spawned-out male and two possibly spawned-out females were examined by us out of a total of nine apparently spawned-out fish set aside by the commercial fishermen during the 1979 fall catch.

It appears that during autumn the commercial fishery in the Colville Delta harvests essentially the non-spawning segment of the arctic cisco population. Domestic fishing at the village of Kaktovik also harvests the non-spawning segment of the arctic cisco population (Griffiths et al. 1977), and the situation is presumably the same for the village of

Nuiqsut (Upper Colville Delta) since at least a portion of their fishing occurs in the lower Colville Delta (see 'Domestic Fisheries'). Effects of domestic and commercial fishing pressure on the Colville stock are not known.

Jim Helmericks, the commercial fisherman, also provides interesting information about the distribution of fish and timing of fish runs in the Colville Delta. Over the years, he has observed that arctic cisco run heaviest in the "east Channel" (Station A, Figure 6) in early winter while least cisco and humpback and broad whitefish tend to use the "Main Channel" (Station B, Fig. 6). He also notes that the arctic cisco run starts about the third week of October with a few peaks of activity through early November.

Additional information on the commercial fishery is presented in 'Influence of Other Organisms'.

Food Habits. Principal foods of arctic cisco in the Simpson Lagoon area are mysids (*Mysis litoralis*, *M. relicta*) and amphipods (*Apherusa glacialis*, *Pontoporeia affinis*). Mysids accounted for 70-87% of their summer diet in 1977 and 1978, whereas a single amphipod species (*Pontoporeia affinis*) was the major prey eaten in winter (Table 28). At other coastal locations, the diet of arctic cisco is generally similar to that found in the present study although proportions of food groups vary and additional food items are sometimes important in the diet; these other groups include copepods, larval fish, chironomid larvae, and polychaetes (Furniss 1975; Kendel et al. 1975; Griffiths et al. 1975, 1977; Percy 1975).

In the Mackenzie Delta, it has been observed that arctic cisco cease feeding while on spawning runs (Stein et al. 1973; Percy 1975); however, many fish in the non-spawning segment of the Colville population continue feeding through the winter. The percentage of fish with some food in their stomachs in early winter was 47% (n = 289 for 1976-79 combined) and 95% (n = 42) in late winter.

Table 28. Foods of arctic cisco in summer (Simpson Lagoon) and winter (Colville Delta, April/May 1978).

	% Composition (Wet Weight)			
	Summer		Winter	
Food Item	1977	1978	Large Fish	Medium Fish
MYSIDS				
Mysis litoralis	19.4	49.1	-	*
Mysis relicta	5.4	29.8	-	-
Remnants	45.0	8.0	-	-
AMPHIPODS				
Apherusa glacialis	10.5	0.8	-	-
Halirages mixtus	-	1.0	-	-
Onisimus glacialis	5.4	4.3	-	-
Onisimus spp.	6.8	-	-	-
Gammarus setosus	0.5	*	-	-
Parathemisto spp.	0.1	1.1	-	-
Pontoporeia affinis	-	*	68.2	94.7
Pontoporeia femorata	-	-	*	-
Gammarocanthus loricatus	*	*	-	-
Gammaridae	1.6	-	-	-
Remnants	0.5	4.1	31.8	3.0
COPEPODS	4.5	0.6	-	-
ISOPODS	0.3	*	-	-
CUMACEAN	*	*	-	-
EUPHAUSIID	*	0.7	-	-
FISH	-	0.2	-	-
MISCELLANEOUS SPP.	*	0.2	-	2.2
No. Stomachs Examined	55	52	24	16
Mean Size Fish (mm)	360	342	317	173

*< 0.1%

Bering Cisco

The Bering cisco (*Coregonus laurettae*) is a species similar in appearance to the arctic cisco. The taxonomical distinction between these two coregonids is briefly reviewed in order to establish their relative importance in the study area.

The North American distributions of these fishes are almost allopatric (McPhail 1966). The Bering cisco occurs primarily along the Bering Sea coast and the arctic cisco is found along the Beaufort Sea coast. The species overlap only between Point Barrow and the Colville River.

McPhail (1966) found that a single meristic character, the number of gill rakers on the lower limb of the first arch, differentiated arctic cisco (26-30 gill rakers) from Bering cisco (21-25). Furthermore, when the cisco were subsequently divided into two groups on this basis, they were also found to differ significantly in mean numbers of lateral line scales and pyloric caeca. Most importantly, in the coastal area where these two groups overlapped, the frequency distribution of gill rakers remained bimodal, suggesting that the "two groups of *autumnalis* ciscoes do not intergrade along the arctic coast in Alaska, but exist sympatrically and therefore, should be considered as valid species".

Data from the present study support this taxonomic distinction (Fig. 41). Almost all ciscoes from Simpson Lagoon had high gill raker counts (arctic cisco), but a selected group of fish from the Colville Delta had low counts (Bering cisco).

Gill raker counts for 241 Simpson Lagoon fish ranged from 22 to 31. While this range exceeds the previously reported range for arctic cisco (26-30) and overlaps with that for Bering cisco (21-25), the sample is as unimodal as one could expect in a natural population. It is biologically unreasonable to divide this sample into two groups on the basis of a 25-26 gill raker criterion. These data indicate that, with increased sample sizes, the intraspecific range of gill raker numbers in arctic cisco is larger than formerly reported. Probably all but the one fish with only 22 rakers from Simpson Lagoon are arctic cisco.

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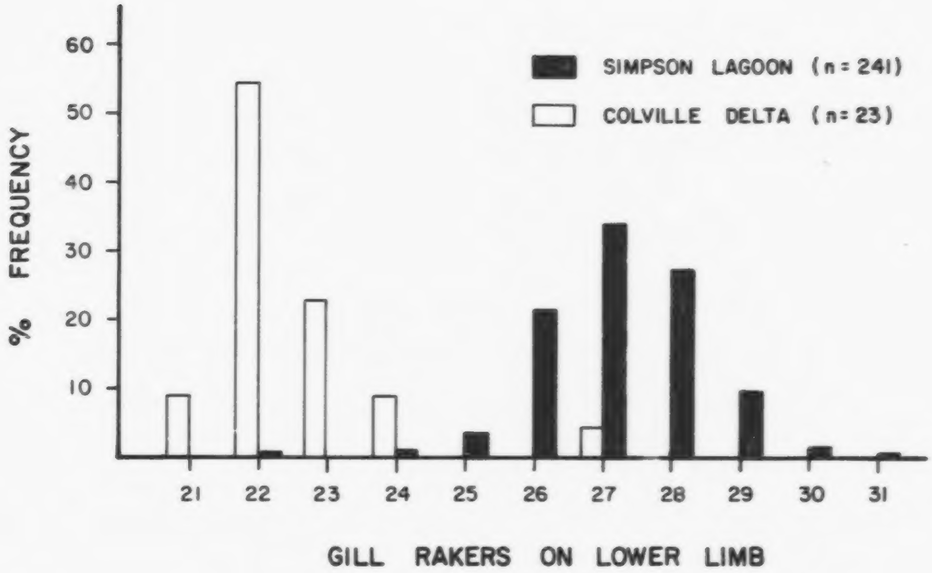

Figure 41. Frequency distribution of number of gill rakers (lower limb, first arch) for samples of arctic and Bering cisco caught in Simpson Lagoon and a selected sample from the Colville Delta.

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The Colville Delta sample represents 23 fish we obtained from the commercial fisherman (J. Helmericks) after we requested a sample of "Bering cisco". Helmericks caught these fish during the fall of 1978. Gill raker counts of these fish correspond to the previously reported counts for Bering cisco with the exception of one fish that had 27 gill rakers. What is significant here is that 22 of the 23 fish were "correctly" selected by eye out of the fishery's catch, which consisted predominantly of arctic and least ciscoes.

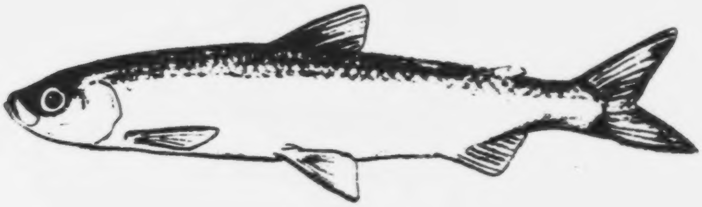
A noticeable difference between the two species is that Bering cisco are stouter or thicker than arctic cisco. This observation is substantiated by a comparison of length-weight relationships for the two species. Relationships for the two species caught together in the Colville Delta fishery are:

Bering cisco: Log Weight (g) = 4.737 + 2.961 Log Length (mm)
$n = 23$, $r = 0.98$

arctic cisco: Log Weight (g) = 5.909 + 3.390 Log Length (mm)
$n = 78$, $r = 0.95$

These regressions are significantly different (ANACOVA; F adjusted means = 26.1, $P < 0.001$; t slope = -1.13, $P > 0.05$); Bering cisco are heavier for a given length.

Least Cisco



The least cisco (*Coregonus sardinella*) is a common anadromous species along portions of the Beaufort Sea coastline. It is generally abundant from Barrow to Prudhoe Bay and also near the Mackenzie River, but scarce between these two areas. The fish were moderately abundant in Simpson Lagoon. They accounted for 1-48% of fish catches by various gear during the open-water season (Table 4). The relative abundance of this species in the lagoon may be higher if, as postulated in the 'Fish Movements' section, a late season run of fish back to overwintering sites occurred after sampling efforts ended.

Freshwater Sources of Least Cisco. Several Beaufort Sea drainages support populations of anadromous least cisco. The best known of these is the Colville River where a small commercial fishery has caught least cisco for years (see 'Commercial Fishery' in 'Influence of Other Organisms'). This study also documented that least cisco overwinter in the Colville drainage and, more importantly, that least cisco spawn in the lower reaches of this river (Appendix 2).

Alaskan streams to the east of the Colville do not support populations of least cisco (e.g., Ward and Craig 1974; Craig 1976; Bendock 1977), but runs of this species occur in several streams to the west of the Colville. Recent surveys in this western region found that least cisco were abundant in many lakes and streams (Hablett 1980).

Tagging data from this study and from nearby Prudhoe Bay (Bendock 1977) suggest that many least cisco captured in marine waters of the study area originate in the Colville River (see 'Fish Movements'). In addition, one fish tagged in Simpson Lagoon was recaptured at a fishing camp near Barrow (specific recapture site unknown) late in the fall. Perhaps this fish originated in a stream to the west of the Colville.

Size Distribution. The size range of least cisco captured in Simpson Lagoon was 80-414 mm; most fish measured 280-340 mm in both 1977 and 1978 (Fig. 42). Fyke nets sampled a wider size range of fish than gill nets, but both methods caught primarily large fish. Small least cisco were not abundant, in contrast to the numerous small arctic cisco found in the study area.

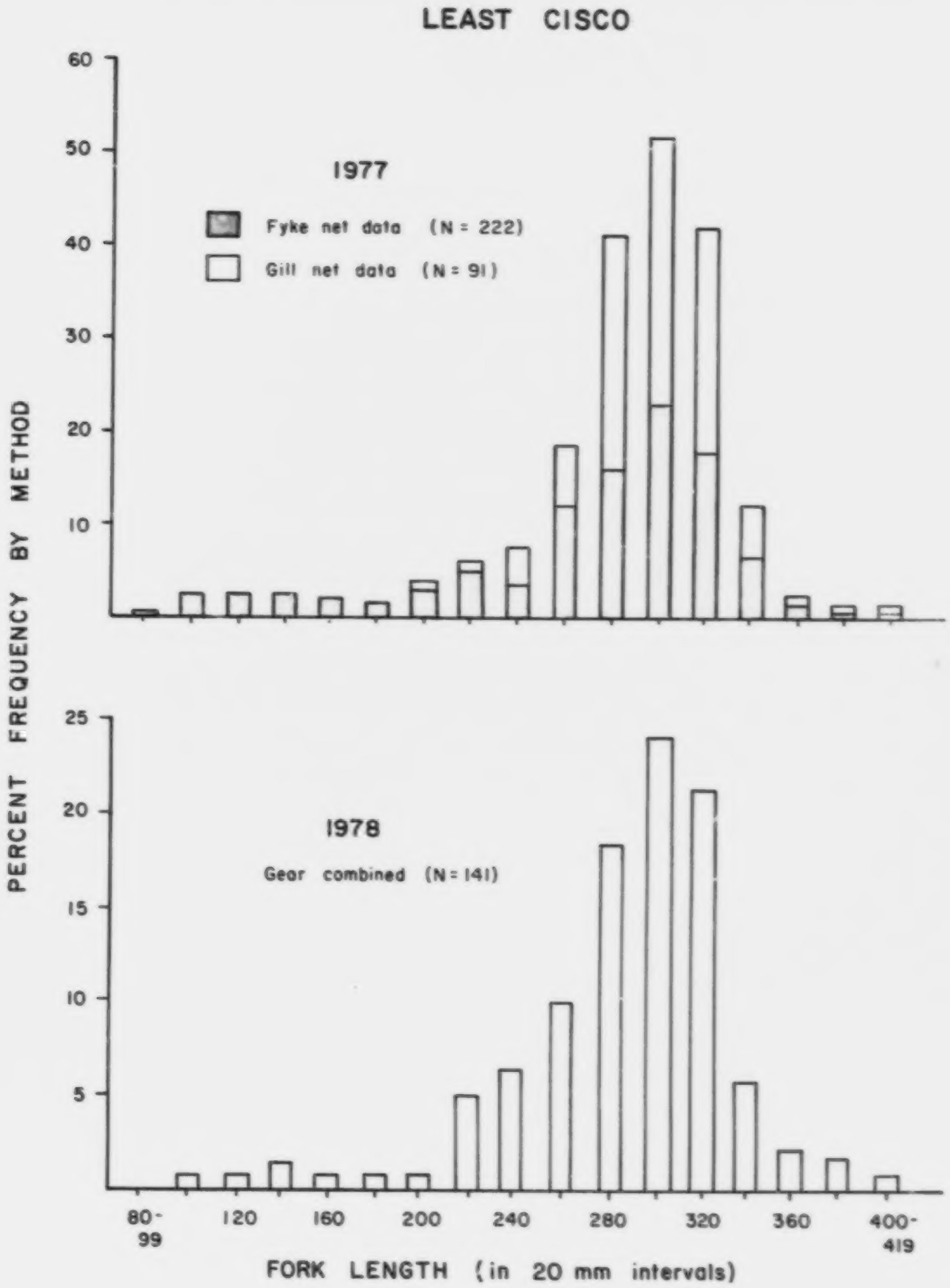


Figure 42. Length frequencies of least cisco caught in Simpson Lagoon, 1977 and 1978. Open and shaded bars in the 1977 diagram each total 100%.

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Age, Growth and Maturity. Though least cisco ages in the sample cover a wide range (Table 29), no fry or age 1 fish were present, and older fish aged 7-11 comprised most of the catch. The growth rate of these fish is generally similar to that reported for least cisco at other Beaufort Sea coastal stations.

Age at maturity was 6-7 for males and 7-10 for females (Table 29). Of the females captured, 73% were mature (64% spawners and 36% non-spawners); of the males, 55% were mature (88% spawners and 12% non-spawners). Because the spawning cycle of least cisco is not fully understood, assessments of their state of maturity are subject to the same problems previously outlined for the arctic cisco. Thus, field assessments of maturity were aided by analyses of seasonal patterns in gonad development (Fig. 43) which are similar to those recorded for this species at Kaktovik Lagoon (Griffiths et al. 1977).

It is apparent that some females captured in coastal waters during summer would spawn in fall since their egg sizes were large (0.9-1.8 mm) and similar to those of known spawners caught in a September survey in the lower Colville drainage (Fig. 43 and Appendix 2). Likewise, many males in the coastal sample would spawn in fall since their stage of gonad development was similar to that of known spawners in fall. Mature green least cisco remain in coastal waters later in the summer than do mature green arctic cisco (cf. Fig. 39).

Some Age and Maturity Comparisons with Arctic Cisco. A comparison of age structure and maturity of least and arctic cisco indicates somewhat different life strategies for the two closely related species. Least cisco tend to grow more slowly, mature sooner and live longer than arctic cisco (Fig. 44). Older least cisco average 50-60 mm smaller at each age than arctic cisco. Perhaps some of this difference reflects the slightly earlier age at which least cisco reach sexual maturity, in that energy would be directed towards reproductive tissue rather than growth. Ages at which approximately 50% of the fish (sexes combined) reached maturity were 7 for least cisco and 8 for arctic cisco (Tables 26 and 29). Age structures of the coastal populations also indicate that few arctic cisco live longer than age 10 while 27% of the least cisco were older than that.

Table 29. Age-length relationship (derived from otoliths) and age-specific maturity of least cisco in Simpson Lagoon, 1977.

	Fork Length (mm)				Maturity			
					Males		Females	
Age	n	mean	(range)	SD	n	% Mature	n	% Mature
2	10	126	(95-154)	19	7	0	3	0
3	5	154	(128-180)	20	2	0	3	0
4	5	197	(163-260)	38	2	0	2	0
5	5	227	(188-291)	38	2	0	3	0
6	5	261	(229-297)	30	2	50	3	0
7	13	277	(239-320)	24	2	100	11	55
8	10	303	(279-320)	12	2	100	8	75
9	19	304	(268-380)	26	3	100	16	81
10	19	305	(263-354)	24	4	100	15	100
11	18	327	(288-399)	24	4	100	12	100
12	8	329	(302-346)	14	0	-	8	100
13	4	322	(305-331)	12	0	-	3	100
14	2	370	(328-412)	59	0	-	2	100
15	1	371	-	-	1	100	0	-
16	0	-	-	-	0	-	0	-
17	0	-	-	-	0	-	0	-
18	1	414	-	-	0	-	1	100
Overall	125				31	55%		73%

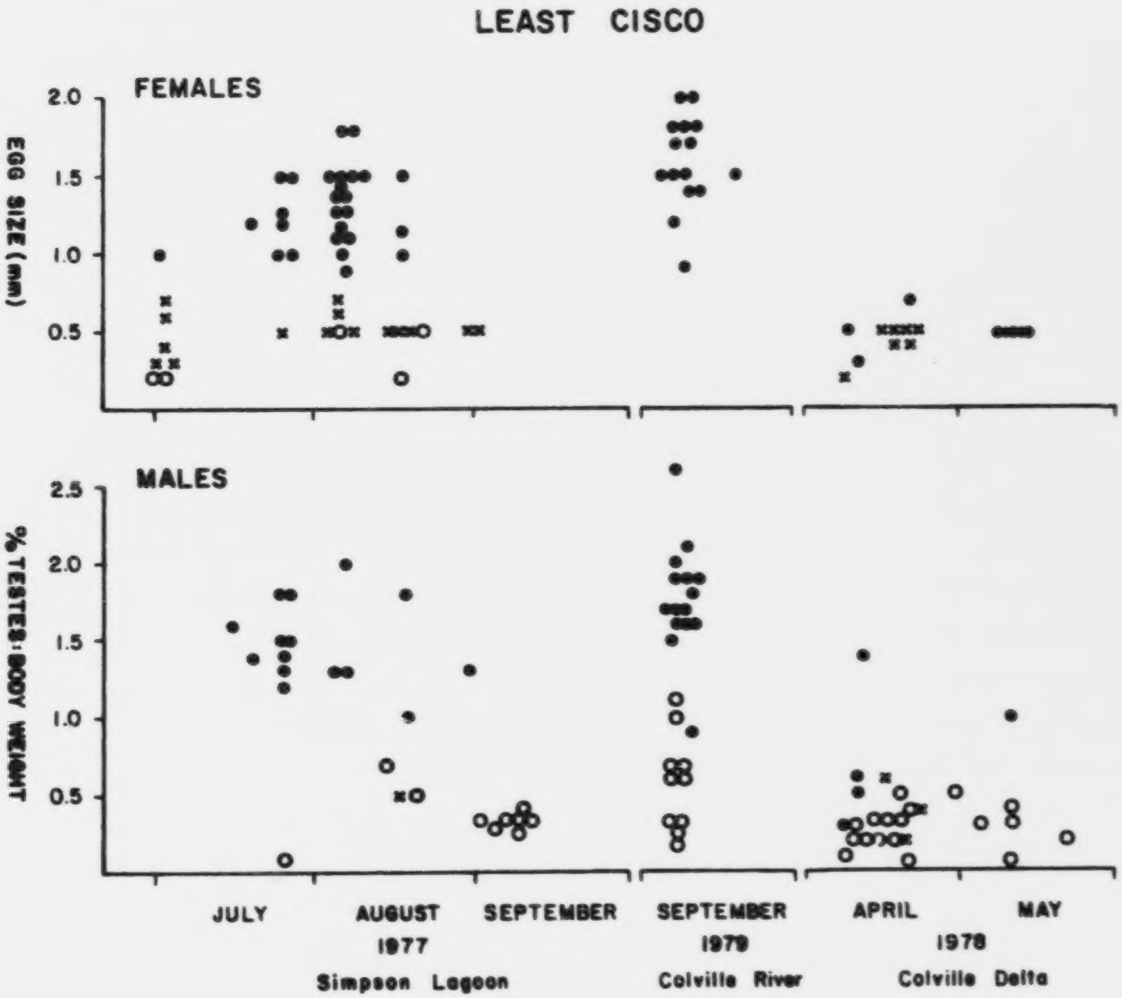

Figure 43. Seasonal changes in reproductive organs of least cisco at three locations. Symbols: immature fish (open circles), mature green fish (closed circles), mature non-spawners (x).

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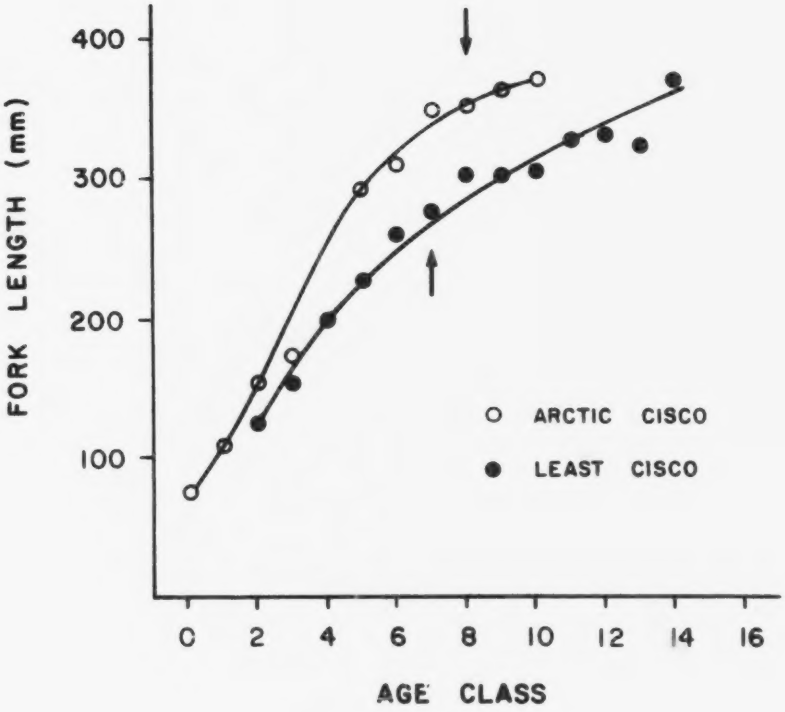

Figure 44. Comparison of arctic and least cisco growth patterns. Arrows indicate ages at which approximately 50% of the fish have reached sexual maturity.

Spawning Locations. Spawning least cisco from both anadromous and lake-resident stocks were taken at several locations in the lower Colville drainage during September 1979. These data are presented in Appendix 2.

Length-Weight. The following length-weight regression was obtained for combined coastal collections of least cisco:

$$\text{Log Weight (g)} = -5.151 + 3.070 \text{ Log Length (mm)}$$
$$n = 384,\ r = 0.97$$

Sex Ratio. Females were significantly more abundant than males in the 1977 Simpson Lagoon sample ($n = 121$, 75% female; $\chi^2 = 28.8$, $P < 0.001$). These results indicate either that females have a greater tendency than males to become anadromous or that females live longer than males, since most older fish were females (Table 29).

Overwintering Areas. Overwintering information is similar to that described for arctic cisco. In our area, the brackish waters (18-32‰) of the Colville Delta are used by both species during winter months. Least cisco are present in the delta during early winter (October-December), as documented by the commercial fishery, and also in late winter, as shown by our results from 8 April-22 May 1978 near Anachilik Island. During the latter period we caught 42 least cisco under the ice (Stations A and B in Fig. 6; described in 'Winter Distribution').

Length-frequencies of the late winter catch (Fig. 45) indicate that the predominant size classes here were somewhat smaller than those in Simpson Lagoon. Similarly, there were proportionally fewer fish older than age 8 in the late winter sample compared to the coastal sample (Table 30). Part of this difference between samples may reflect the movements of some mature green fish (i.e., older and larger fish) found in Simpson Lagoon during summer to upstream spawning and overwintering sites in the Colville drainage.

Both mature and immature fish were present in the late winter sample:

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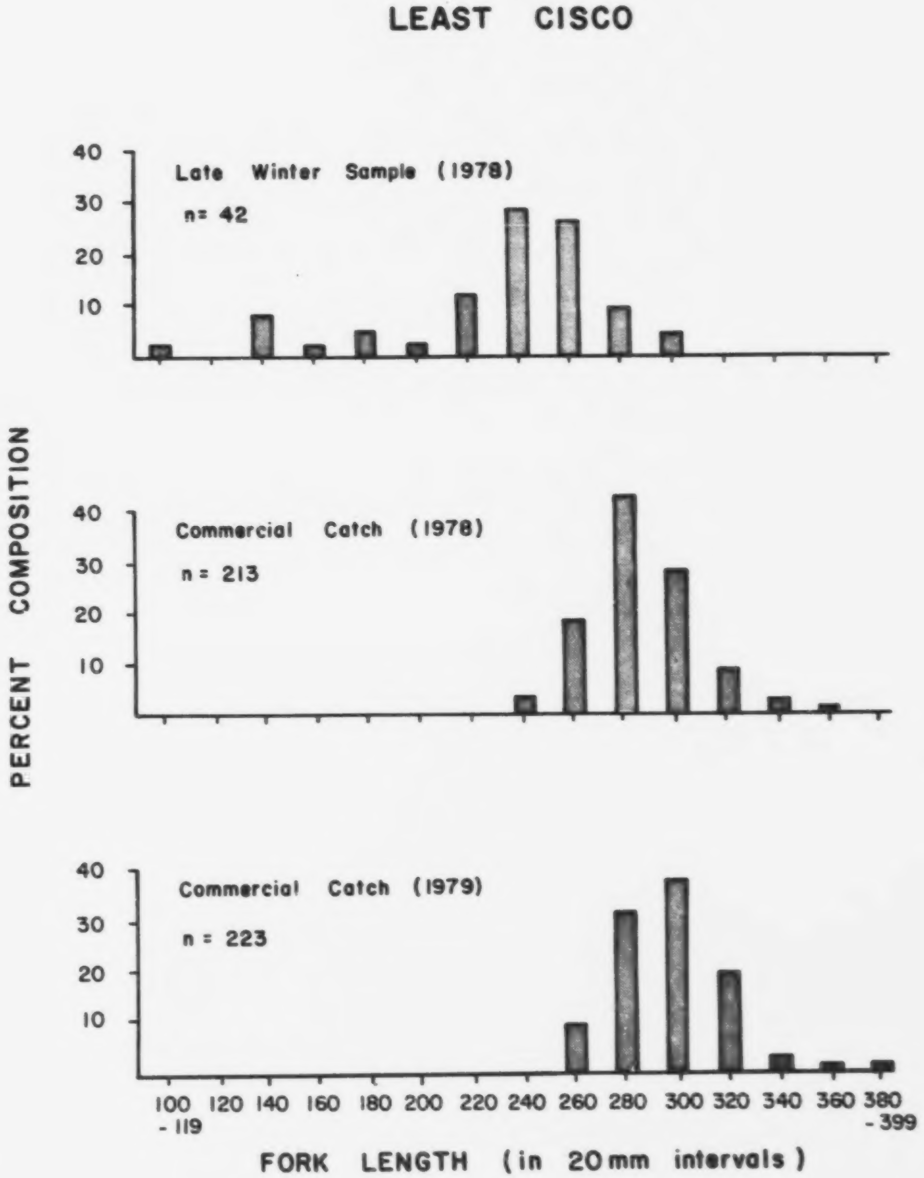

Figure 45. Length frequencies of least cisco caught in the Colville Delta in winter.

Table 30. Age composition of winter-caught least cisco in the Colville Delta.

	% Composition	
Age	Late Winter Survey April/May 1978	Fall Commercial Catch (Helmericks) 1978
2	4.8	-
3	7.1	-
4	7.1	-
5	2.4	-
6	16.7	7.4
7	9.5	14.8
8	38.1	28.4
9	2.4	8.6
10	2.4	7.4
11	4.8	7.4
12	-	11.1
13	2.4	4.9
14	-	4.9
15	2.4	-
16	-	2.5
17	-	1.2
18	-	1.2
No. Fish	42	81

	Number of Fish		
	Immature	Mature Green	Mature Non-spawner
females	1	5	10
males	18	5	3

However, assessments of maturity are especially tentative at this time of year since developmental stages of gonads appear similar for the various life-history stages of fish (Fig. 43).

The only other Beaufort Sea data regarding overwintering least cisco are from the Mackenzie River region. Least cisco overwinter in the lower Mackenzie Delta (Mann 1975) and a few have been caught in nearby coastal waters: Shingle Point (Steigenberger et al. 1975), 3 km offshore of Tibjak Point along the Tuktoyaktuk Peninsula (Galbraith and Hunter 1979), Kugmallit Bay and Mallik Bay (Percey 1975). Salinities at the last two sites, 0.2‰ and 4.9-7.9‰, were much lower than in the Colville Delta (18-32‰), indicating a wide salinity tolerance for overwintering least cisco.

The Commercial Fishery in the Colville Delta. The commercial fishery (Helmericks) catches large least cisco similar in size to those in Simpson Lagoon (Fig. 45). These fish ranged 6-18 years in age but most were ages 7-12 (Table 30). They tended to be older than the arctic cisco taken in the same fishery (cf. Table 27).

Although measurements of egg sizes and testes weights were not made, most least cisco were judged to be mature fish in non-spawning or spawned-out condition:

		% Composition			
Year	n	Immature	Mature Non-Spawner	Mature Green	Mature Spawned-out
1978	213	7	84	0	9
1979	224	1	46	13	40

It thus appears that the commercial fishery harvests principally the non-spawning and spawned-out segment of the least cisco population.

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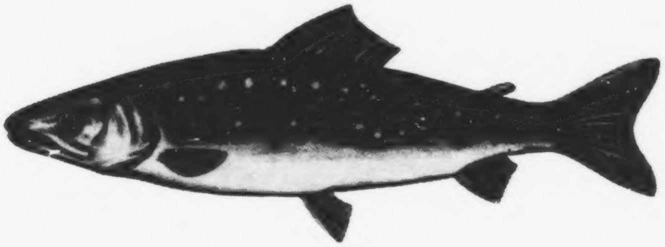
Additional information on the commercial fishery is presented in 'Influence of Other Organisms'.

Food Habits. The foods eaten by least cisco are very similar to those eaten by arctic cisco. Mysids (*Mysis relicta*, *M. litoralis*) accounted for 66-69% of their summer diets in Simpson Lagoon during 1977 and 1978; amphipods (especially *Pontoporeia affinis*) were the major prey in the Colville Delta during winter (Table 31). These data are similar to those obtained at other coastal locations although proportions of food groups in other areas varied and additional food groups, especially copepods, larval fish and insects, were occasionally important (Furniss 1975; Kendel et al. 1975; Griffiths et al. 1975, 1977; Percy 1975).

Many least cisco in the Colville Delta continued eating during winter months. The percentage of fish with some food in their stomachs was 65% (n = 224) in October-December 1979 and 97% (n = 33) in April and May 1978.

Arctic Char



The arctic char, *Salvelinus alpinus*, is a common species of North Slope rivers and the Beaufort Sea coastline. It is a prized sport fish and is also important in native domestic fisheries. The life history of this species has been reviewed be several authors (Craig and McCart 1976; Craig 1977; McCart 1980).

Table 31. Foods of least cisco in summer (Simpson Lagoon) and winter (Colville Delta, April/May 1978).

Food Item	% Composition (Wet Weight) Summer 1977	Summer 1978	Winter 1978
MYSIDS			
Mysis litoralis	8.9	29.8	-
Mysis relicta	28.5	33.5	-
Remnants	31.7	3.1	-
AMPHIPODS			
Apherusa glacialis	0.7	-	-
Onisimis glacialis	4.6	19.1	-
Onisimus sp.	1.0	-	-
Gammarus setosus	1.0	0.4	-
Parathemisto spp.	*	-	-
Pontoporeia affinis	0.4	5.8	42.9
Pontoporeia femorata	1.3	-	-
Gammarocanthus loricatus	2.6	0.2	-
Gammaridae	3.2	-	-
Remnants	6.3	7.7	57.1
COPEPODS	8.7	-	-
ISOPODS	0.1	0.2	-
CUMACEAN	0.6	*	-
FISH	0.3	0.2	-
MISCELLANEOUS SPP.	0.2	-	-
No. Stomachs Examined	51	27	23
Mean Size Fish (mm)	307	302	267

*< 0.1%

Char caught in Simpson Lagoon during this study probably originated from several North Slope drainages, but it is likely that many are from the nearby Sagavanirktok River. This river supports one of the largest char populations on the Alaskan North Slope and tagging evidence shows that some Sagavanirktok char do enter Simpson Lagoon (Appendix 1). Undoubtedly, some char in Simpson Lagoon are also from the Colville River, although the size of the Colville char population appears to be relatively small (Hablett 1980). Beaufort Sea drainages west of the Colville do not appear to support char populations (Hablett 1980); these streams apparently lack groundwater habitats, which play an important role during char spawning and overwintering (e.g., Craig 1977).

Size Distribution. Fork lengths of char in Simpson Lagoon ranged from 120-703 mm. Fyke nets caught primarily small char 200-260 mm long, corresponding to juveniles aged 3-5. Gill nets also sampled this group of juveniles, but caught large char as well (Fig. 46). A distinctly bimodal size distribution is evident; since gill nets caught both small and large char, it is probable that intermediate-sized fish were not present. These missing intermediate size-classes correspond to fish ages 5-8, some of which would be first-time spawners. Their poor representation in Simpson Lagoon may be due to weak year classes and/or a tendency, hypothesized by some investigators, for some spawning char to remain in fresh water during the year they will spawn.

Age, Growth and Maturity. Age, growth and reproductive condition of arctic char in Simpson Lagoon are generally similar to those of char taken in other coastal areas in Alaska and the Yukon Territory. Simpson Lagoon char ranged in age from 3-15 (Table 32). Here, as in other areas, char younger than age 3 were generally absent in coastal waters since juveniles spend several years in fresh water before smolting. Char aged 4 and 10 were especially abundant in Simpson Lagoon.

Female char exhibit a greater tendency than males to become anadromous (Craig and McCart 1976), thus accounting for the predominance of females in our samples (n = 143, 71% female; $\chi^2 = 24.3$, $P < 0.001$). Female char attain maturity at ages 7-8, and males by age 9 (Table 32).

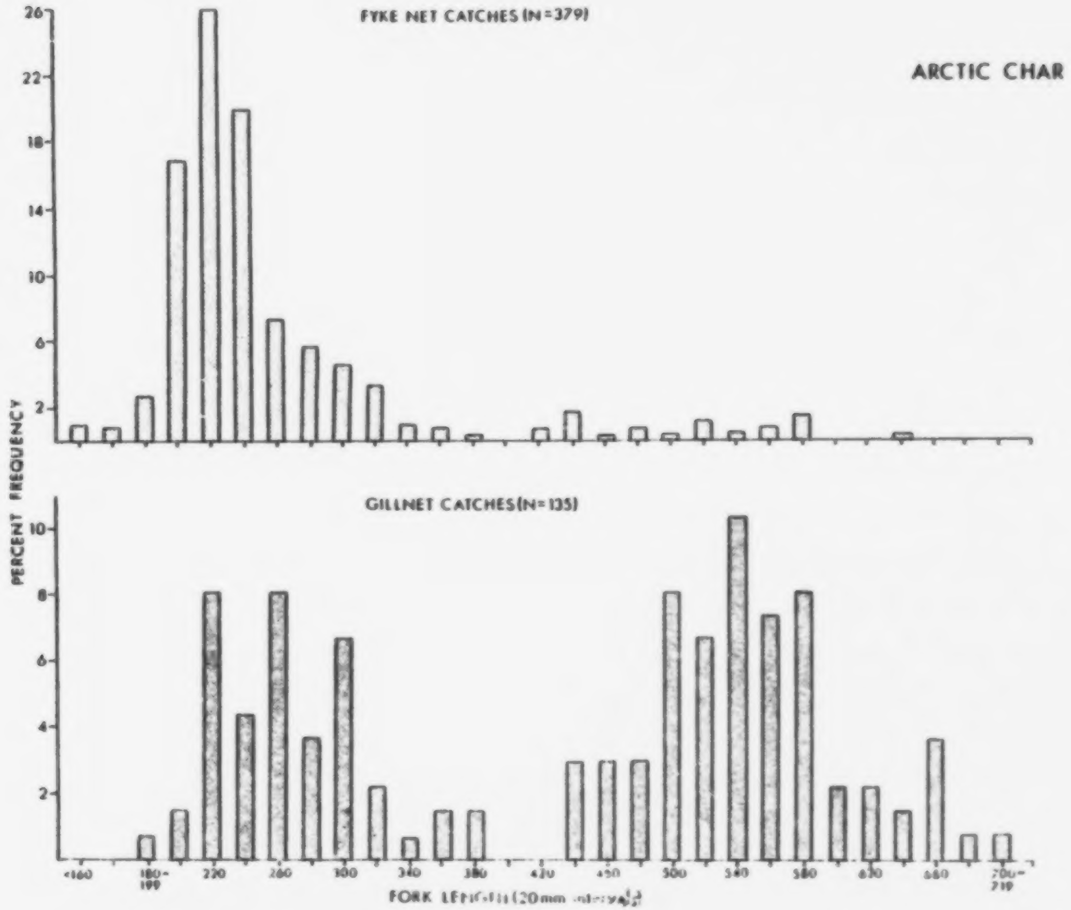


Figure 46. Length-frequency of arctic char caught in Simpson Lagoon, 1977. Gill net and fyke net data are presented separately.

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Table 32. Age-length relationship (derived from otoliths) and age-specific maturity of arctic char in Simpson Lagoon, 1977.

	Fork Length (mm)				Maturity			
					Males		Females	
Age	n	mean	(range)	SD	n	% Mature	n	% Mature
3	14	233	(181-315)	34	5	0	9	0
4	31	254	(189-329)	35	9	0	19	0
5	18	298	(238-364)	33	7	0	11	0
6	5	356	(305-473)	70	3	0	2	0
7	5	390	(298-454)	63	0	-	5	40
8	5	507	(473-539)	30	0	-	5	100
9	9	524	(475-614)	47	1	100	8	100
10	21	554	(480-640)	42	7	100	14	100
11	12	586	(527-662)	46	3	100	9	100
12	6	582	(542-680)	51	2	100	4	100
13	5	608	(520-703)	79	2	100	3	100
14	2	643	(595-690)	67	1	100	1	100
15	1	668	-	-	1	100	0	-
Overall	134				41	41%	90	51%

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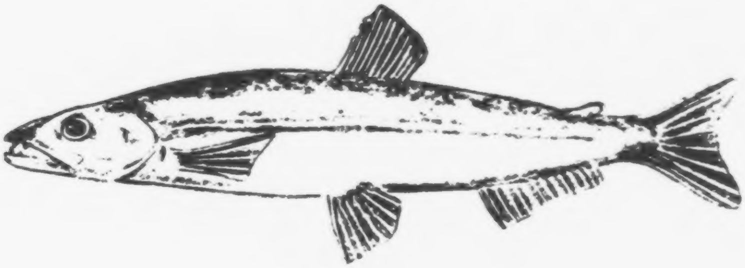
Approximately half of the char caught in Simpson Lagoon were mature fish (51% of the females and 41% of the males were mature).

Seasonal patterns in egg development and testes weight for the various life-history stages of char are shown in Fig. 47. The large eggs of some females (up to 3.0 mm) in early summer were nearly the size of eggs at spawning time (3.5-4.5 mm) indicating that these fish would spawn in the coming fall. Craig (1977) also reports that at least some female char enter coastal waters for a short period during the same year in which they will spawn. Fish which had previously spawned but would not spawn in the coming fall were also caught in early summer. Egg sizes of these fish were 1.0-2.0 mm. Of the mature females caught in summer, 46% were spawners and 54% were non-spawners.

The pattern of gonad condition for male char was similar to that of females (Fig. 47). Mature green fish were present in coastal waters for the first part of the summer. The percent testes:body weights of these fish ranged from 0.9-3.3%, compared to values of 0.05-0.45% for immature fish and mature non-spawners. Of the mature males, 29% were spawners and 71% non-spawners.

Food Habits. In 1977, the diet of arctic char consisted largely of amphipods (78%), but mysids were the major food item of char (89%) the following summer. Principal species eaten were *Gammarus setosus*, *Apherusa glacialis*, *Onisimus glacialis*, *Mysis litoralis* and *Mysis relicta* (Table 33).

Boreal Smelt



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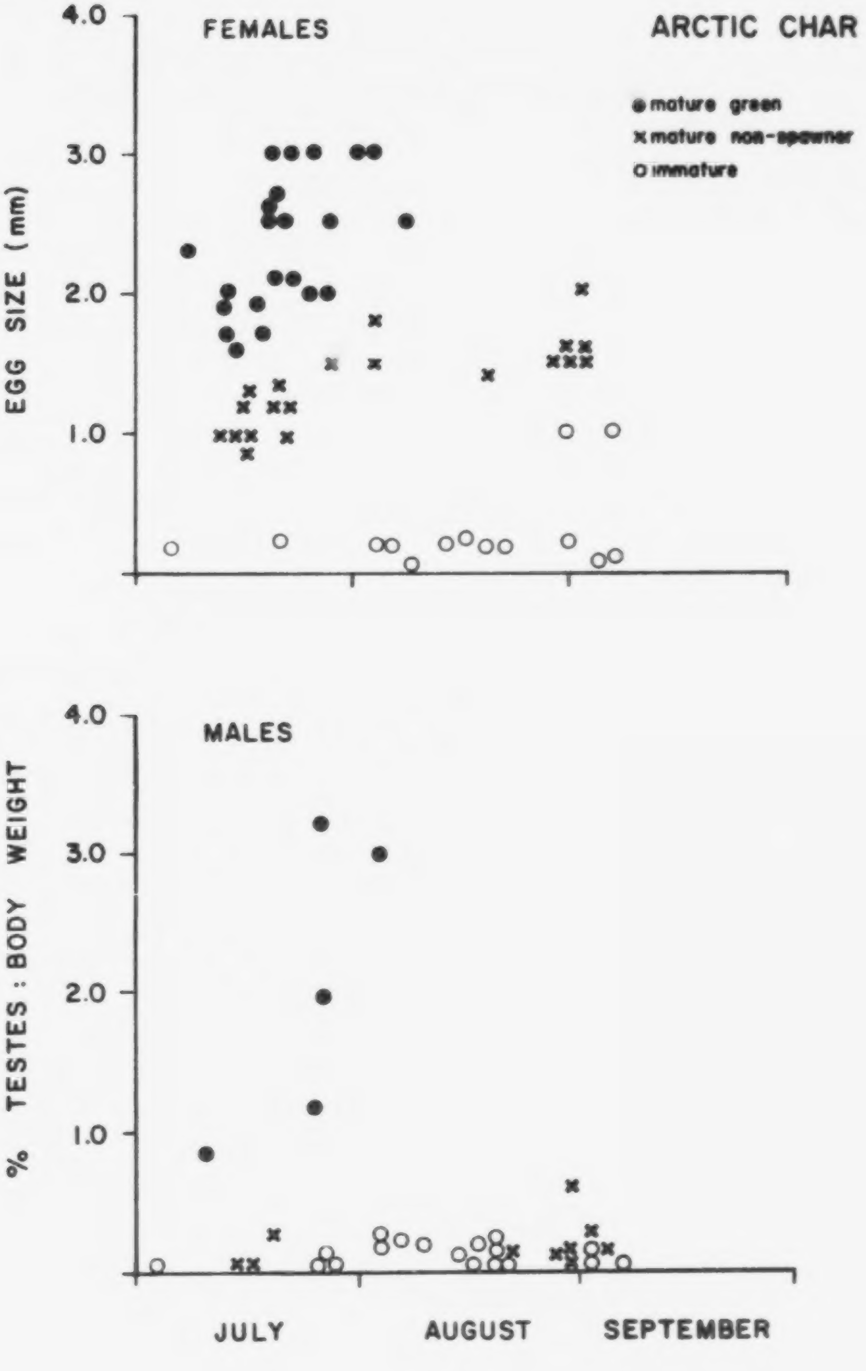

Figure 47. Seasonal pattern of egg size and testes:body weight ratios of arctic char in Simpson Lagoon. Symbols: immature fish (open circles), mature green fish (closed circles), mature non-spawners (x).

Table 33. Foods of arctic char in Simpson Lagoon in summer, 1977 and 1978.

Food Item	% Composition (Wet Weight)	
	1977	1978
MYSIDS		
Mysis litoralis	3.8	54.4
Mysis relicta	1.1	16.7
Remnants	10.6	18.3
AMPHIPODS		
Apherusa glacialis	3.9	-
Apherusa sp.	5.0	-
Halirages mixtus	-	*
Onisimus glacialis	4.8	1.1
Onisimus sp.	2.2	-
Gammarus setosus	9.7	0.5
Gammaridae	18.3	-
Parathemisto spp.	3.0	*
Pontoporeia affinis	0.2	*
Pontoporeia femorata	0.1	-
Gammarocanthus loricatus	0.3	0.1
Remnants	30.6	2.6
COPEPODS	1.3	-
ISOPODS	0.2	0.1
CUMACEAN	0.2	*
EUPHAUSIID	2.8	-
FISH	1.6	5.8
POLYCHAETE	*	0.2
MISCELLANEOUS SPP.	0.3	-
No. Stomachs Examined	50	17
Mean Size Fish (mm)	475	331

*< 0.1%

In our study area, boreal smelt are anadromous fish that live in marine waters and enter fresh water in springtime to spawn. Though a relatively minor component of the nearshore fish community in summer, boreal smelt were one of the most abundant species caught in winter.

Taxonomists do not agree on the naming or status of this species; we will accept the convention suggested by McPhail and Lindsey (1970), wherein all North American forms are included in the species complex *Osmerus eperlanus*. Others, notably Scott and Crossman (1973), prefer to designate two subspecies--the Pacific-Arctic form (*Osmerus eperlanus dentex*) and the Atlantic form (*O. eperlanus mordax*). Another common name for this fish is the rainbow smelt.

The Pacific and arctic distribution of boreal smelt is essentially continuous from Vancouver Island around Alaska to Cape Bathurst in the Canadian arctic. In the Atlantic region they occur from Labrador to Virginia, and large populations are found in the Great Lakes watershed (McPhail and Lindsey 1970; Scott and Crossman 1973). Coastal populations of *O. eperlanus* are anadromous; however, complete freshwater life cycles occur in many landlocked populations.

Relatively few boreal smelt were caught in Simpson Lagoon during the open-water season. The 22 fish caught in 1977 and the 1049 fish caught in 1978 constituted less than 1% of the total catch each summer. Fish using nearshore waters at this time tended to be small, immature fish (Fig. 48). In winter, larger boreal smelt were caught and they accounted for a higher percentage of the total catch in the Colville Delta (13%) and coastal areas of the Beaufort Sea (57%).

In the winter, boreal smelt gathered near the mouth of the Colville River. The catch per unit effort at this location ranged from 5.8-22.2 fish compared to 0-0.5 fish at other coastal sites (Table 11). Presumably these fish migrate into the Colville Delta in springtime to spawn. A similar concentration of boreal smelt also occurs off the Kuk River Delta near Wainwright in winter (Bendock 1977). In Siberia, anadromous populations ascend the Yenisei River before the ice breaks and spawn in the river in May or June (McPhail and Lindsey 1970). It appears that the Colville River population follows a similar schedule.

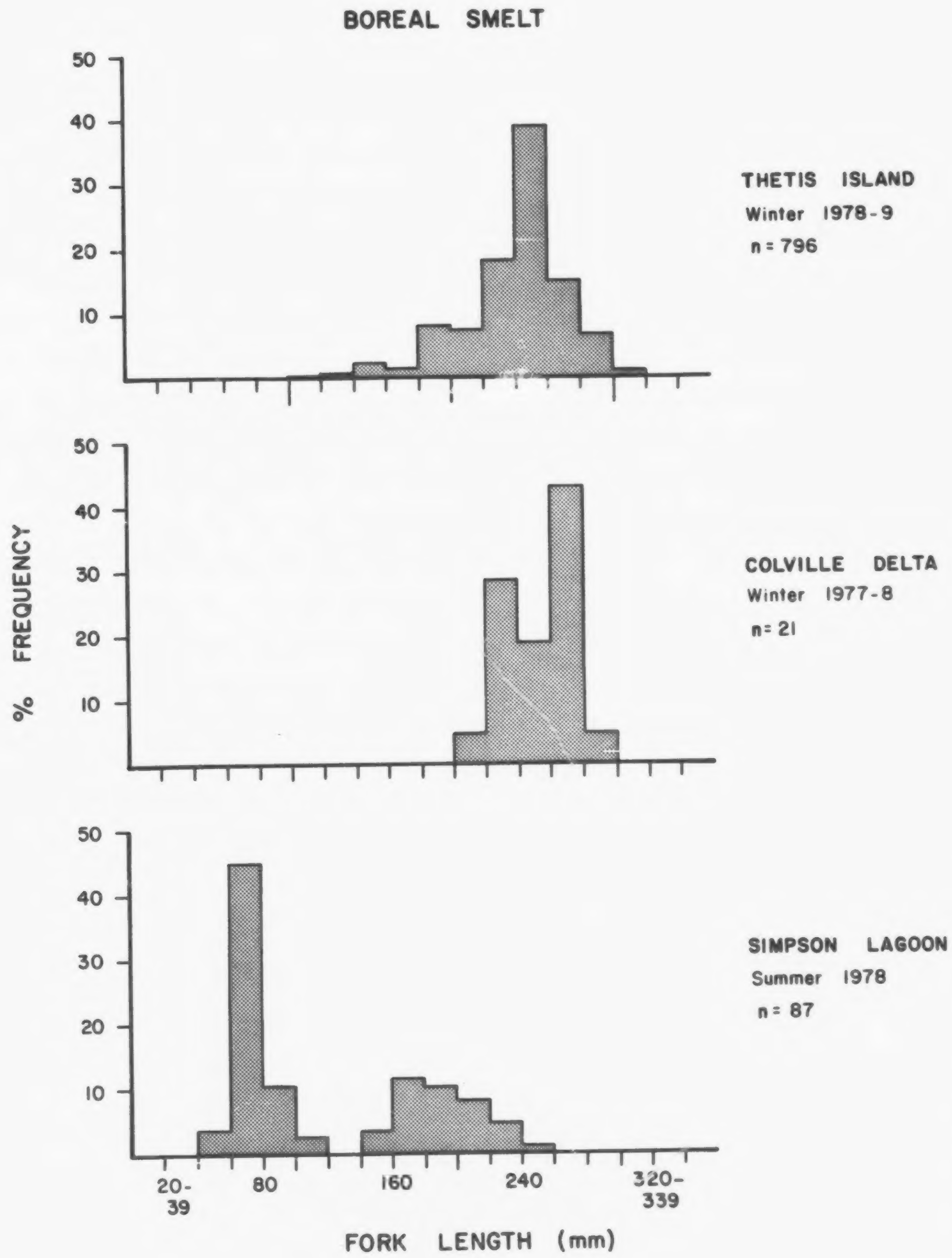

Figure 48. Length frequencies of boreal smelt.

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Age and Growth. Ages of boreal smelt were determined by otoliths (Table 34). Data are presented for combined sexes, since size at age did not differ significantly for males and females.

Boreal smelt in the study area are slow-growing and long-lived. Growth of these fish is generally similar to other northern populations but slower than fish from Lake Superior (Fig. 49). The Simpson Lagoon-Thetis Island fish grow slowly and steadily, reaching maximum sizes of about 300 mm at ages 13-15. The longevity of these fish is markedly greater than in other populations of this species. Fish aged 5, 8 and 9 were the oldest fish caught, respectively, in the Miramichi River, N.B. (McKenzie 1964), the Mackenzie Delta (Percy 1975) and Prudhoe Bay (Bendock 1977). Reasons for this difference are not known but a contributing factor is probably the season of capture--the older fish taken in our study were caught in winter, a time when relatively few fish were taken in other studies. Our summer catches were, like those of other workers, mostly fish aged 1-6, but our winter catches were predominantly fish aged 7-12.

The following length-weight regression was calculated for 362 fish in the study sample (r = 0.96, size range 130-305 mm):

$$\log_{10} \text{Weight (g)} = -5.81 + 3.32 \log_{10} \text{Length (mm)}$$

This length-weight relationship is very similar to that for an anadromous population in the Parker River Estuary in Massachusetts where Murawaski and Cole (1978) found the relationship to be

$$\log_{10}W = -6.03 + 3.36_{10}L$$

However, it is quite different from the relationship

$$\log_{10}W = 2.58 + 2.95 \log_{10}L$$

that Bailey (1964) reported for Lake Superior smelt. The two anadromous populations both increased in weight at a greater rate than the fresh water population (slopes 3.32 and 3.36 compared to 2.95).

Reproduction. Males reach sexual maturity by age 5 and females at ages 5 (possibly 4) to 7 (Table 34). These ages are generally older than the ages at maturity reported for other populations of boreal

Table 34. Age-length relationship and age-specific maturity of boreal smelt in coastal waters near the Colville River, 1978-79. Ages were determined by otoliths.

					Maturity			
		Fork Length (mm)			Males		Females	
Age	n	x̄	(range)	SD	n	% Mature	n	% Mature
1	22	74	(56-89)	9	0	-	0	-
2	4	116	(90-142)	21	0	-	1	0
3	2	148	(143-152)	6	0	-	1	0
4	4	166	(159-172)	5	1	0	0	-
5	24	186	(163-211)	15	8	100	11	18
6	6	206	(170-222)	20	0	-	5	60
7	11	230	(210-258)	14	4	100	5	100
8	37	241	(198-270)	16	12	100	22	100
9	8	251	(227-272)	18	3	100	5	100
10	3	276	(262-295)	17	0	-	3	100
11	14	271	(243-290)	12	4	100	10	100
12	4	290	(285-300)	7	1	100	2	100
13	2	287	(270-304)	24	0	-	2	100
14	1	285	-	-	0	-	0	-
15	1	305	-	-	0	-	1	100
Totals	143				33		68	

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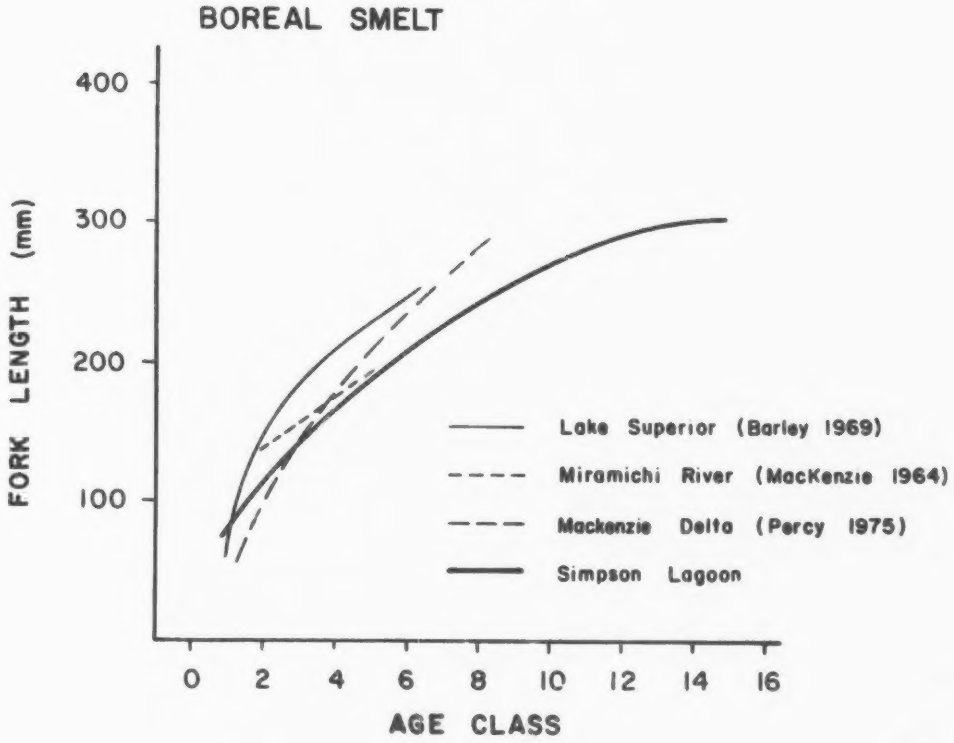

Figure 49. Comparisons of growth patterns of boreal smelt from the Simpson Lagoon - Thetis Island area with populations from other areas.

smelt: age 2 (Miramichi River), ages 3-4 (Yenisei River, Siberia; McPhail and Lindsey 1970), age 4 (Prudhoe Bay), and age 6 (Mackenzie River).

All of the mature fish taken in our study area had well-developed gonads by early winter. Ovary weights increased through the winter to 16-20% of body weight while testes weights remained fairly constant at 3-5% of body weight:

	$\bar{x}$ Gonad : Body Weight			
	Males		Females	
Time	%	(n)	%	(n)
August 78	4.9	(6)	2.3	(6)
November 78	3.5	(12)	6.4	(23)
February 79	4.2	(28)	13.1	(26)
March 79	3.6	(29)	16.0	(40)
*April 78	3.4	(6)	20.0	(15)
May 79	3.7	(1)	17.1	(7)

*Colville Delta

Several of these fish (1 male, 7 females) possessed paired gonads of very different sizes.

Egg diameters of mature females increased steadily from late summer to late winter: 0.3-0.5 mm in August (n = 5), 0.5 mm in November (n = 22), 0.8-0.9 mm in February (n = 17), and 0.8-1.0 mm in April (n = 15). Bailey (1964) reports that the eggs are 0.9-1.0 mm in diameter at spawning time.

Boreal smelt spawn in fresh or brackish water but not in marine water, which kills their eggs (Bigelow and Schroeder 1963). The timing of the spawning run depends on local conditions. In general, they ascend spawning streams before or at spring breakup and commence spawning when the freshets slacken (McKenzie 1964). In the Beaufort Sea near the Colville River, boreal smelt continued to be abundant at the Thetis Island station through the first week in May. They then abruptly disappeared, an event that coincided with the arrival of melt water from the Colville (see 'Fish Movements'). If the breakup of the Colville does induce an upriver migration with subsequent spawning, this population would not spawn until sometime in June under normal conditions. The

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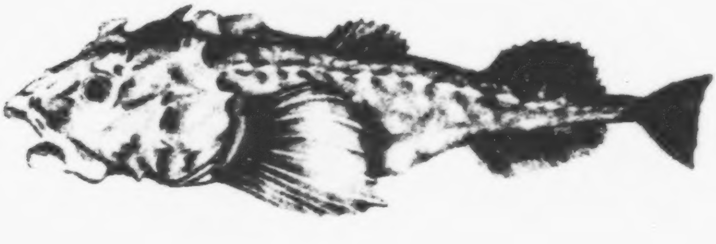
melt-water run-off experienced in May 1979 was an unusually early event; melt-water normally reaches the sea early in June.

Food Habits. Principal foods of winter-caught boreal smelt were mysids (*Mysis litoralis*, *M. relicta*), amphipods (*Onisimus glacialis*) and fish (arctic cod). These data are presented in Table 22, 'Feeding Ecology'. Many fish in this November 1978 sample from Thetis Island had food in their stomachs. However, fewer fish continued eating as the winter progressed:

	% empty stomach	(n)
November	20	(84)
February	67	(61)
March	97	(35)
May	100	(51)

Other workers have also noted a high incidence of empty stomachs in this species, particularly around spawning time (Percy 1975; Stern et al. 1973).

Fourhorn Sculpin



Of all the marine fishes found along the Beaufort Sea coastline, the fourhorn sculpin (*Myoxocephalus quadricornis*) is among the most widespread and numerous. These demersal sculpins are found in virtually all nearshore habitats, including the deeper waters not frequented by anadromous species.

Fourhorn sculpins in the 1977 Simpson Lagoon sample ranged in total length from 18-265 mm and their length-frequency distribution largely reflected the sampling methods used in this study. Seines collected young-of-the-year along the shoreline, fyke nets caught primarily intermediate-size sculpins, and gill nets caught large fish (Fig. 50). This bias in sampling methods accounts for some of the observed variations in size distributions of this species at other coastal locations where only one or two of the above-mentioned gear types were used to collect fish. It does appear, however, that large sculpins are less abundant in Simpson Lagoon than in areas to the east of the study area. Modal sizes of fish taken by gill net in Simpson Lagoon were 160-200 mm compared to 200-240 mm at Nunaluk Lagoon (Griffiths et al. 1975), Kaktovik Lagoon (Griffiths et al. 1977) and the outer Mackenzie Delta (Percy 1975). In addition, maximum sizes of fourhorn sculpins were smaller in Simpson Lagoon.

Fourhorn sculpin young-of-the-year averaged 21.4 mm in length (range 18-26 mm, n = 50) on 3 August 1977. At this time, their distribution along the lagoon shore of Pingok Island was examined. Densities were determined by seining seventeen 20 m^2 plots (see 'METHODS') at three distances from the shoreline:

Distance from Shore (m)	Water Depth (cm)	No. Plots Sampled	Sculpin Fry Density (No./m^2) Mean (Range)
0-2	0-10	7	1.5 (0.1-3.0)
3-5	10-25	5	3.9 (0.3-9.6)
10-12	30-35	5	0.1 (0-0.2)

The capture data showed that the young-of-the-year were distributed close to shore, with greatest densities recorded 3-5 m from the shoreline.

Growth and Maturity. Growth and maturity patterns of fourhorn sculpins in Simpson Lagoon (Table 35) differed in several ways from patterns in Nunaluk and Kaktovik lagoons (Griffiths et al. 1975, 1977). Age-length relationships indicated a faster growth rate for the study

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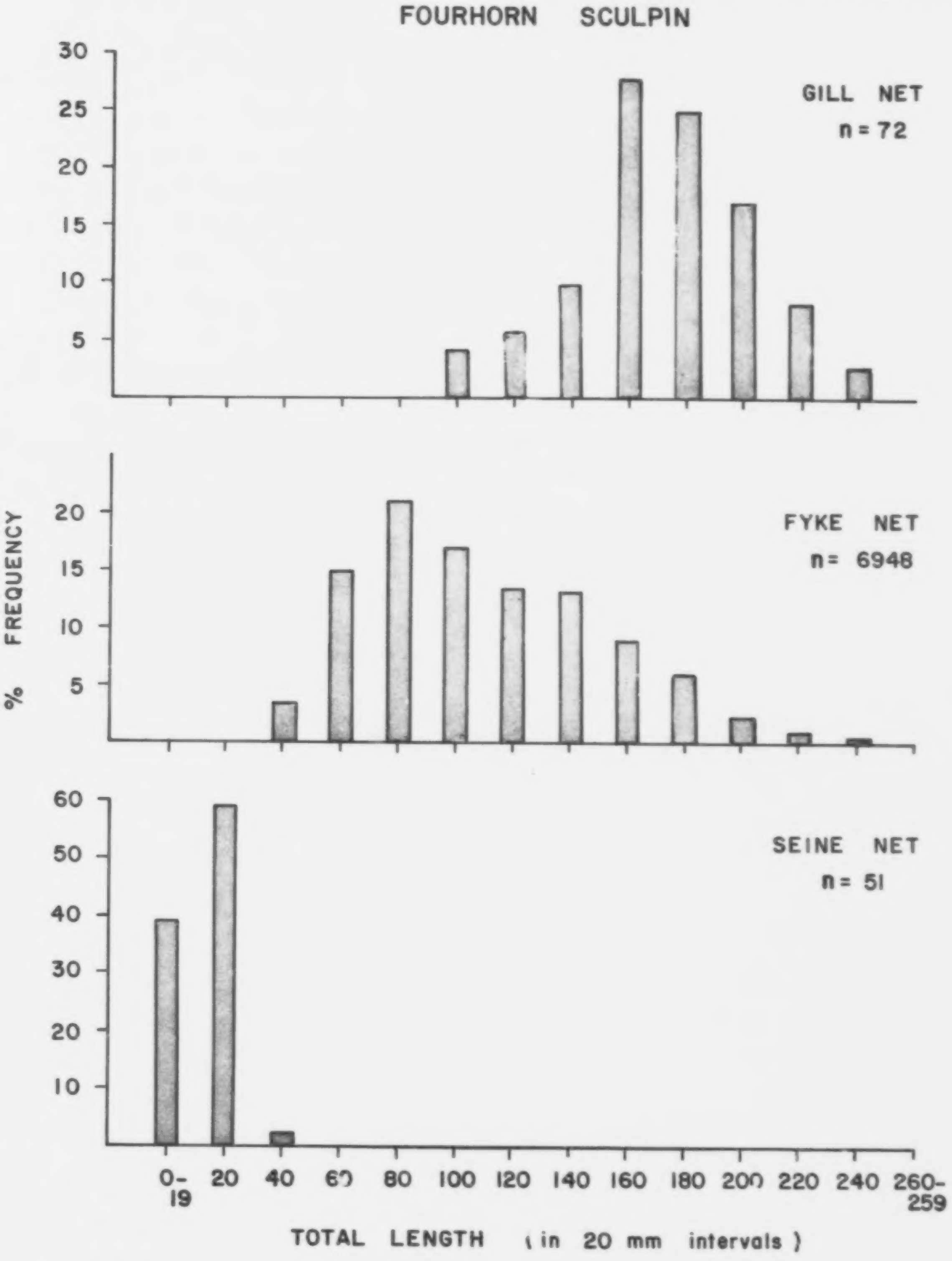

Figure 50. Length-frequencies of fourhorn sculpin caught by three sampling methods in Simpson Lagoon, 1977.

Table 35. Age-length relationship and age-specific maturity of fourhorn sculpin in Simpson Lagoon, 1977. Ages were determined by otoliths.

	Total Length (mm)				Maturity			
					Males		Females	
Age	n	$\bar{x}$	(range)	SD	n	% Mature	n	% Mature
1	55	63	(46- 81)	8	7	0	22	0
2	46	94	(74-160)	15	15	20	26	0
3	34	134	(102-167)	17	14	86	20	0
4	31	169	(133-208)	17	10	100	21	71
5	31	193	(168-224)	14	10	100	21	95
6	24	211	(176-248)	18	2	100	21	100
7	5	222	(197-258)	25	0	-	5	100
8	3	236	(220-265)	25	1	100	2	100
9	1	226	-	-	1	100	0	-
Overall	231				60	65%	138	47%

population, and these fish reached sexual maturity 1-3 years earlier than those in Nunaluk or Kaktovik lagoons.

Sexual maturity was determined on the basis of field examination, aided by an analysis of growth trends in egg sizes and testes weights (Fig. 51). Female sculpin matured between the ages of 4-6 and appeared to spawn annually thereafter. Their egg sizes increased through the open-water season, reaching sizes of 1.0-2.2 mm in September and November. Eggs measure 2.0-2.9 mm at spawning (Andriyashev 1954; Westin 1968).

Some male fourhorn sculpins were mature as early as age 2 and all were mature by age 4. Although testes of the smallest mature males weighed only 1.0 g, these fish were judged to be mature because of the appearance of the gonads and relatively large proportion of the body cavity filled by the testes. These general criteria were also followed in the Nunaluk and Kaktovik lagoon studies (Griffiths et al. 1975, 1977). Testes weights of the Simpson Lagoon sample, as a percentage of body weight, varied from 2.6-16.7% in summer. After spawning, this percentage dropped to 1.0-3.2%.

Reasons for the accelerated growth and relatively early maturity in the study population are not known. Percy (1975) reports an even faster growth rate for fourhorn sculpins in the Mackenzie Delta.

Sex Ratio. As in studies elsewhere along the Beaufort Sea coast, more female than male fourhorn sculpins were caught in Simpson Lagoon ($n = 225$, 67% female; $\chi^2 = 26.4$, $P < 0.001$).

Length-Weight. The length-weight regression for a sample of fourhorn sculpins from Simpson Lagoon (1977) was:

$$\text{Log Weight (g)} = -6.016 + 3.46 \text{ Log Length (mm)}$$
$$n = 272,\ r = 0.98$$

Spawning and Overwintering. During the winter program, fourhorn sculpins were caught only in the western portion of the study area (see 'Winter Distribution'). The catch per unit effort (CPUE, number of fish per 24 h gill net set) was greatest off the Colville River near Thetis Island:

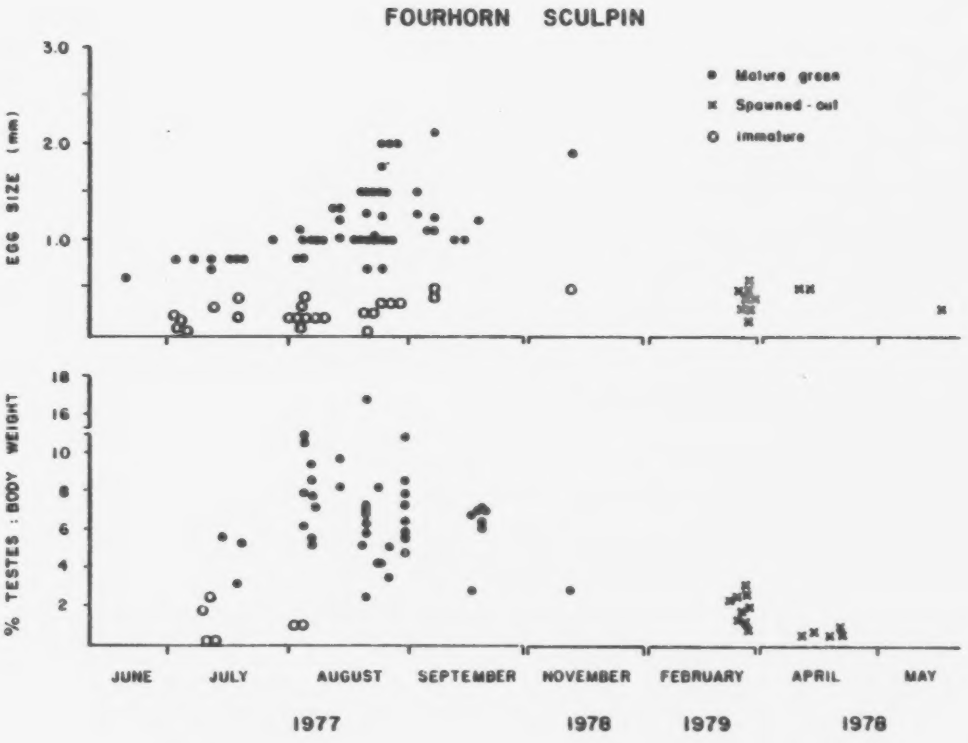

Figure 51. Seasonal patterns of egg size and testes:body weight ratios of fourhorn sculpin in summer (Simpson Lagoon) and winter (Colville Delta, April/May 1978; Thetis Island station, November 1978 and February 1979). Only males 7 g were used in these analyses since smaller immature males occasionally have erratically high values.

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Winter Station	Total Numbers Caught	CPUE
Thetis Island	1021	10.5
Spy Island West	2	0.3
Colville Delta	13	0.2
Other Stations	0	0

Sculpin apparently moved into the Thetis Island area throughout the winter as indicated by an increasing CPUE: 1.2 (November), 6.8 (February), 13.8 (March), 11.7 (April) (Table 11). Spawning occurred in mid-winter at the Thetis Island station--the few fish examined in late November, were not yet ripe but all were spawned-out by late February (Fig. 51).

Fourhorn sculpin overwinter throughout the brackish waters of the Colville Delta. They were caught in the lower delta during our study (Stations A and B, Fig. 6) and Kogl and Schell (1974) caught some overwintering in the upper delta. Areas around the Mackenzie River are also used by fourhorn sculpin in winter. This species has been caught in Mallik and Mason Bays (Percy 1975) and at Shingle Point (Kendel et al. 1975). Salinities at these locations were low (4.9-9.6‰)compared to the Colville Delta (18-32‰) or Thetis Island (24-32‰), indicating a wide salinity tolerance for overwintering fourhorn sculpin.

Food Habits. Fourhorn sculpin eat primarily amphipods and isopods (Table 36). During summer, amphipod species accounted for 81% of the diet; secondary foods were mysids (10%) and isopods (6%). In winter, isopods were the main prey (60-78%); lesser amounts of amphipods (5-31%) and fish eggs (5-9%) were eaten.

Fourhorn sculpin at other coastal locations eat similar food groups, particularly isopods and amphipods (Percy 1975; Kendel et al. 1975; Griffiths et al. 1975, 1977). The sculpin is, in turn, food for a variety of bird and fish predators (McAllister 1961).

Table 36. Foods of fourhorn sculpin in summer (Simpson Lagoon) and winter (Colville Delta, April/May 1978; nearshore coastal waters between Thetis and Narwhal Islands, November/February/April/May 1978-79).

Food Item	% Composition (wet Weight)		
	Summer	Winter	
	1977	1977-78	1978-79
MYSIDS			
Mysis litoralis	1.7	-	1.8
Mysis relicta	1.9	-	
Remnants	6.1	-	1.2
AMPHIPODS			
Apherusa glacialis	*	-	0.3
Onisimus glacialis	13.8	-	-
Onisimus sp.	4.9	-	-
Gammarus setosus	4.5	-	-
Gammaridae	3.1	-	-
Parathemisto spp.	1.7	-	-
Pontoporeia affinis	0.2	13.8	1.2
Pontoporeia femorata	0.1	-	1.5
Gammarocanthus loricatus	3.3	-	-
Remnants	49.1	16.8	1.4
COPEPODS	*	-	*
ISOPODS	6.1	60.2	78.4
CUMACEAN	*	-	0.7
FISH	3.3	-	0.5
FREE EGGS	*	9.2	5.0
POLYCHAETE	*	-	2.3
MISCELLANEOUS SPP.	0.2	-	5.6
No. Stomachs Examined	65	9	45
Mean Size Fish (mm)	150	193	184

*< 0.1%

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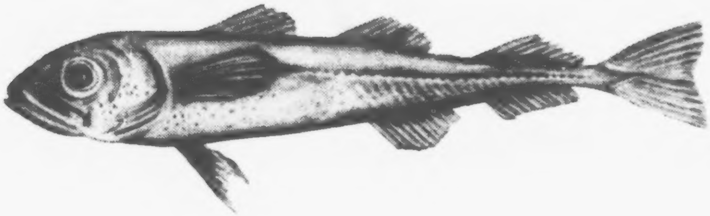
Arctic Cod



The arctic cod (*Boreogadus saida*) is an integral element in trophic pathways of the Beaufort Sea. It has been described as a "key species in the ecosystem of the Arctic ocean" because of its abundance, widespread distribution and importance in the diets of marine mammals, birds and other fish (Andriyashev 1964; Quast 1972; Bradstreet 1977; Bain and Sekerak 1978). Coastal residents at Barrow and Kaktovik also catch arctic cod in early winter for human and dog food.

Distribution and Movements. Although the distribution of arctic cod is often associated with the occurrence of ice, catch data show that these fish are present in ice-free nearshore waters. During summer months, young-of-the-year were collected in the study area (Table 7), Prudhoe Bay (Bendock 1977) and Kaktovik Lagoon (Griffiths et al. 1977). Young-of-the-year also occur at distances approximately 50-150 km offshore in the Beaufort and Chukchi seas (Quast 1974; Horner 1978).

Older arctic cod (principally juveniles ages 1-3) were abundant in Simpson Lagoon in August and September. These fish accounted for 8% of the total fyke net catch during the 1977 open-water season and 78% in 1978 (Table 4). Arctic cod were also common in nearby Prudhoe Bay in 1975 and 1976 (Bendock 1977) and they were the most numerous species caught in offshore waters of the northeastern Chukchi and western Beaufort seas (Frost et al. 1978). The arctic cod has not been reported to be an abundant species in most other studies along the coastlines of northern Alaskan and the Yukon Territory, probably because the earlier studies utilized sampling gear (i.e., gill nets) which infrequently capture this species.

The seasonal occurrence of arctic cod in Simpson Lagoon was qualitatively similar during 1977 and 1978 in that few were caught during the first half of the open-water season while many were taken during the second half (Fig. 20). This pattern agrees with that observed in other arctic regions where arctic cod have been observed to migrate from offshore to coastal areas in fall (Andriyashev 1954; Bain and Sekerak 1978). In addition to this late summer increase in cod numbers, a large school of cod swept through Simpson Lagoon in 1978 (see 'Fish Movements'). During 14-22 August, approximately 124,200 arctic cod were caught in the Milne Point fyke net (Fig. 20) and this value was used in rough calculations which suggested that there were 12-27 million cod in the lagoon at this time (see 'Estimated Densities of Combined Species').

Some arctic cod remained in Simpson Lagoon in early winter (see 'Winter Distribution') but all apparently vacated these shallow waters by February. However, nearby deeper coastal areas (Stefansson Sound) were inhabited by cod through the winter.

Size Distribution. Arctic cod caught in Simpson Lagoon and surrounding nearshore waters ranged in length from 6-29 mm for young-of-the-year and from 45-257 mm for older fish. Most of the older fish were 60-180 mm in length and similar sizes were caught during open-water and winter periods (Fig. 52). Almost all of these fish were captured in fyke nets but some were also taken by gill net in early winter. At that time, their body shape changed enough (as their gonads increased in size) so that some were susceptible to capture by gill net.

The sizes of arctic cod in Simpson Lagoon are similar to those recorded in Prudhoe Bay in 1975 and 1976 (Bendock 1977) but are substantially larger than those caught in offshore waters by Frost et al. (1978). Most of the offshore cod, which were caught by otter trawl in water depths of 40-400 m, measured 60-110 mm (total range 45-180 mm).

Age and Growth. Young-of-the-year arctic cod were caught in Faber trawls in Simpson Lagoon and in marine waters seaward of Pingok Island in 1977 (Table 7). Early catches (21 July) averaged 7.8 mm in length

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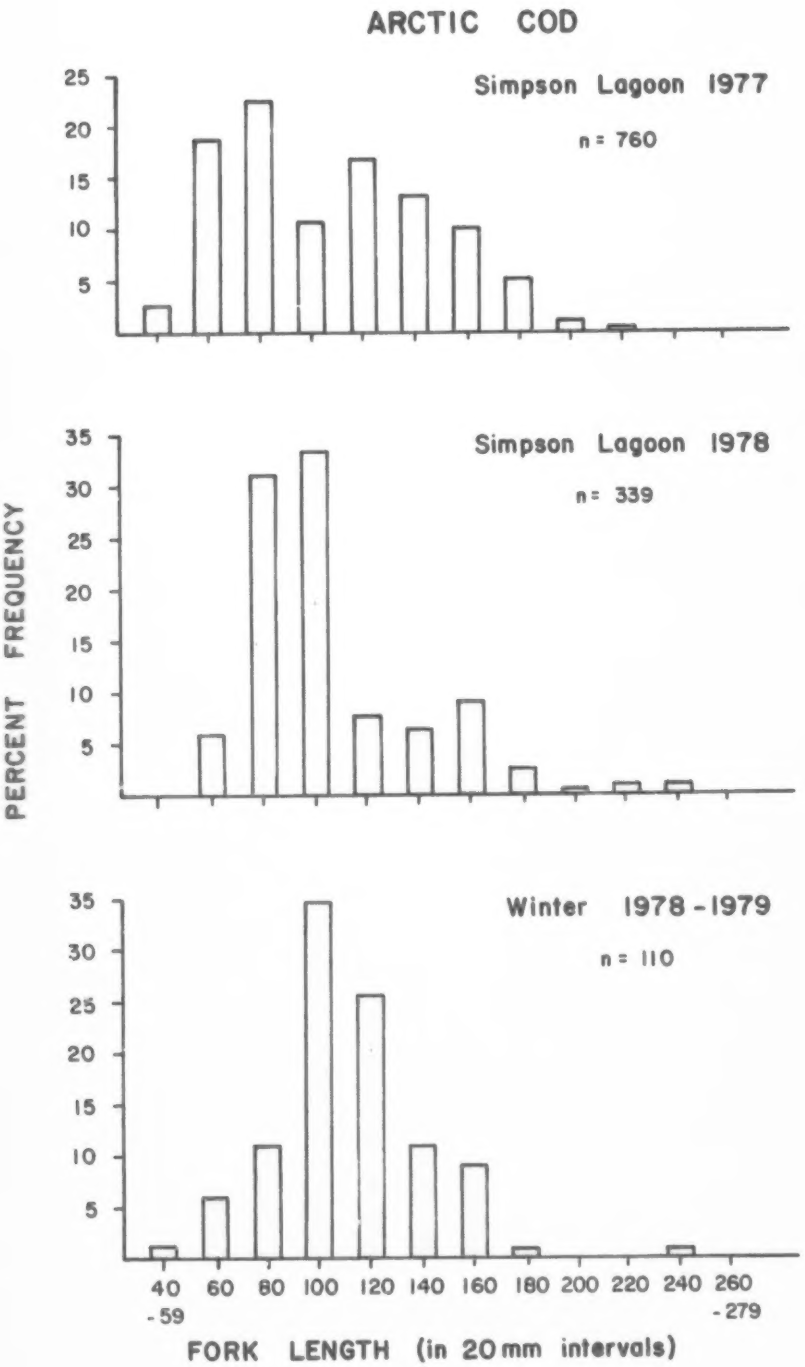

Figure 52. Length frequencies of arctic cod (excluding young-of-year) in Simpson Lagoon (July-September 1977 and 1978) and nearshore waters between Thetis and Narwhal islands (November 1978; February, April, May 1979).

(range 6-11 mm, n = 12 preserved specimens), whereas late season catches (14 September) averaged 19.0 mm (range 12-29, n = 17 preserved specimens). On one occasion when young-of-the-year were collected both inside Simpson Lagoon and 2 km offshore in colder marine waters (14 September), there was no significant difference in the size of the fish (Simpson Lagoon: $n = 12$, $\bar{x} = 18.1$, SD = 4.2; offshore: $n = 6$, $\bar{x} = 21.2$, SD = 3.0; $t = 1.6$, $P > 0.1$). Thus, there was no evidence that growth conditions were better in one area or the other.

Older arctic cod in Simpson Lagoon ranged from 1-6 years old but most were young fish, ages 1-3 (Table 37). Fish aged 4-6 comprised only 7% of the fish collected for age analysis and this is an overestimate of the population value since large fish were selectively chosen for age analysis. Inspection of the length frequencies shows that the sizes corresponding to age 1-3 fish (< 170 mm) account for most of those caught (Fig. 52).

Age-length data for samples of arctic cod caught during the summers of 1977 (n = 199) and 1978 (n = 113) and the winter of 1978-79 (n = 99) are presented for combined samples (Table 37) and separately (Table 38) to illustrate ages of fish present in summer and winter. The sexes were combined since no significant differences were found in the sizes of males and females at age (t tests, $P > 0.1$) during each of the three sampling periods. Size at age was also compared for the two summer periods; the cod tended to be slightly larger at ages 1-5 in 1978 but the difference was significant in the case of only one age class--age 2 cod averaged 15 mm larger in 1978 ($t = 3.6$, $P < 0.001$).

The growth rate of cod in Simpson Lagoon is similar to that reported for other populations of this species caught in Prudhoe Bay (Bendock 1977) and nearshore waters of the Canadian Arctic (Bain and Sekerak 1978). However, the Simpson Lagoon fish were, on the average, 10-28 mm larger at each age compared to fish caught during the same period (August-September 1977) in offshore waters of the Beaufort Sea (Frost et al. 1978). It is tempting to speculate that the warmer coastal waters provide more favorable growing conditions than offshore waters, but the

Table 37. Age-length relationship (derived by otoliths) and sex ratio of combined samples of arctic cod caught in Simpson Lagoon and adjacent coastal waters, 1977-79.

	Fork Length (mm)				Sex Ratio	
Age	n	$\bar{x}$	(range)	SD	n	% Female
1	196	84	(54-110)	13	0	-
2	101	128	(88-177)	20	87	52
3	86	162	(120-196)	19	86	71
4	16	182	(129-203)	21	15	80
5	8	212	(153-250)	36	7	100
6	4	240	(198-257)	28	4	75
	411				199	64%

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Table 38. Age-fork length (mm) comparison for arctic cod caught in summer (Simpson Lagoon) and winter (nearshore coastal waters between Thetis and Narwhal Islands), 1977-79.

	August/September 1977				August/September 1978				November 1978				February 1979				April/May 1979			
Age	n	x̄	(range)	SD	n	x̄	(range)	SD	n	x̄	(range)	SD	n	x̄	(range)	SD	n	x̄	(range)	SD
1	134	82	(54-110)	13	37	85	(64-110)	12	11	106	(103-111)	4	4	75	(65- 82)	7	10	80	(60-100)	12
2	32	129	(106-160)	14	28	144	(114-167)	18	14	121	(106-159)	18	25	114	(90-130)	11	2	102	(88-117)	20
3	28	169	(150-193)	12	32	172	(154-196)	11	9	162	(122-178)	17	17	132	(120-147)	9	0	-	-	-
4	2	189	(183-195)	8	9	192	(182-203)	8	3	177	(170-182)	6	1	129	-	-	1	141	-	-
5	2	190	(160-221)	43	5	233	(224-250)	11	0	-	-	-	1	153	-	-	0	-	-	-
6	1	251	-	-	2	228	(198-257)	42	1	253	-	-	0	-	-	-	0	-	-	-
	199				113				38				48				13			

observed difference may simply reflect a bias in sampling methodology (i.e., nearshore fyke nets versus offshore otter trawls).

The length-weight relationship for summer-caught arctic cod in Simpson Lagoon is

$$\log \text{Weight (g)} = -5.196 + 3.031 \log \text{Length (mm)}$$
$$n = 277,\ r = 0.98$$

Sex Ratio. Females out-numbered males during the open-water season but males were more abundant in winter:

Season	n*	% Female	χ^2	P
1977 summer	62	79	20.9	<0.001
1978 summer	69	80	24.4	<0.001
1978-79 winter	68	35	5.9	<0.025
Totals	199	64%		

*excludes age 1 fish (see text).

Older fish in the study population were primarily females, which accounted for 74% of the 3-6 year olds. The sex ratio was approximately equal at age 2; younger fish were not included in these analyses since developing ovaries in these small fish appeared easier to identify than testes.

Maturity. Assessment of age at sexual maturity was complicated by two factors: (1) most fish caught appeared to be immature, and (2) reproductive organs of mature fish were poorly developed in August and September when most cod were caught. Therefore, age at maturity was determined by considering only those fish that were known spawners or very probable spawners. Known spawners were ripe or spawned-out fish collected during the winter program. Very probable spawners appeared to be approaching spawning condition in late summer and early winter samples. This assessment was based on analyses of egg sizes for females and the ratio of testes weight:body weight for males (Fig. 53).

For the females, estimated egg diameters were generally 0.2-0.5 mm in August and early September. By mid-September, larger eggs (0.8-1.5 mm) were found in 12 female cod. These were considered to be maturing females since the eggs of the only ripe female caught nearly 5 months

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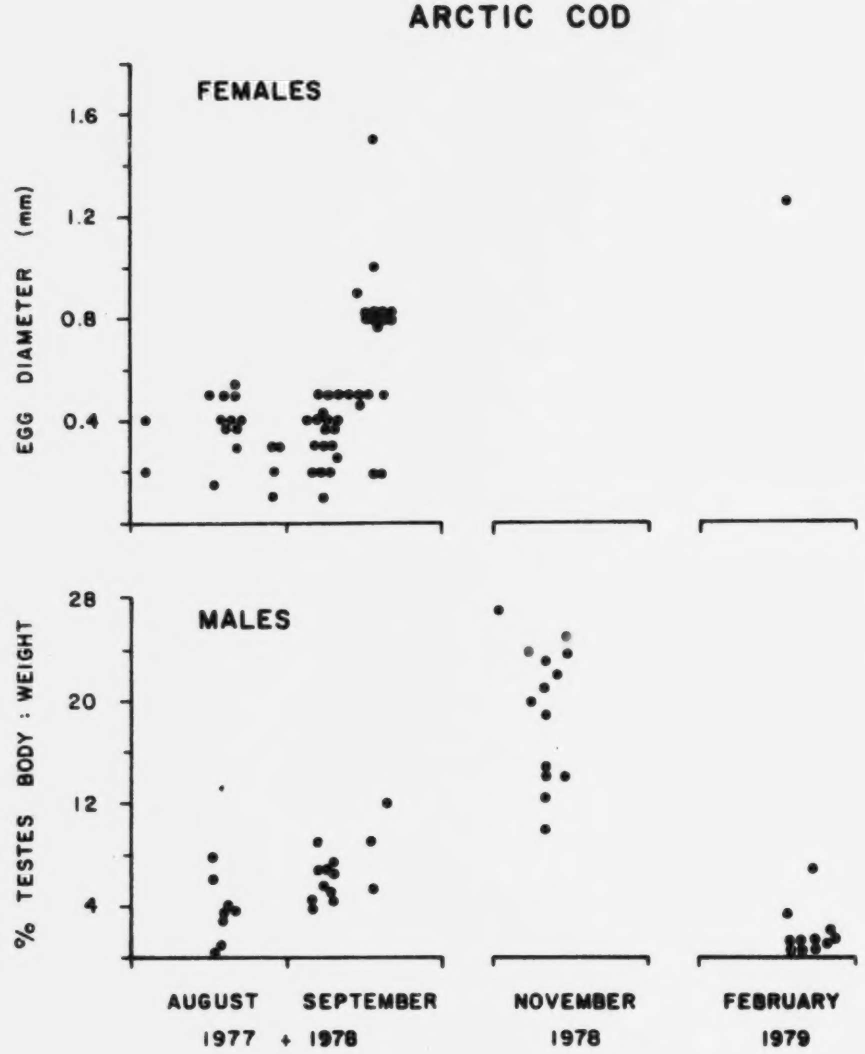

Figure 53. Seasonal pattern of egg sizes and testes:body weight ratios of arctic cod in summer (Simpson Lagoon) and winter (combined nearshore locations).

later (February) measured 1.3 mm. Andriyashev (1954) reports that arctic cod eggs reach 1.6-1.8 mm at spawning time in December and January.

For the males, the ratio of testes weight:body weight showed little increase in August and September. At that time, testes typically accounted for 4-8% of total body weight but these values increased to 10-27% for males judged to be mature in November.

The ages of these known or probable spawners were as follows:

Age	Number of Spawners	
	Males	Females
1	1	0
2	13	3
3	12	10
4	2	1
5	0	2
6	1	1
Totals	29	17

Most mature males were ages 2 and 3 whereas most mature females were age 3. These ages at maturity are earlier than reported (age 4) for this species in the Soviet Union (Andriyashev 1954). The proportion of Simpson Lagoon fish maturing at these young ages is not known. Some male fish classified as definite immatures in November were age 3 (n = 4), and some immature females were age 3 (n = 5), 4 (n = 1), and 6 (n = 1).

Sizes of mature males were generally smaller than for mature females (Fig. 54), as one would expect from the sex differential in ages of maturity. Prior to spawning, most mature males measured 107-160 mm long and their testes weight ranged from 1.4 to 56 g. Mature females tended to be 140-180 mm in length and their ovary weights were 1.2-5.1 g. These fish sizes are considerably smaller than the 200-230 mm (total length) range reported for spawners in Soviet waters (Andriyashev 1954).

Spawning Period and Area. The time of spawning was not pinpointed, but spawning occurred sometime between late November and early February. Fish nearing spawning condition were caught in early winter (5-16 November 1978) and by the next sampling period in February, spawning was essentially complete. At that time (17-23 February 1979), one ripe and two

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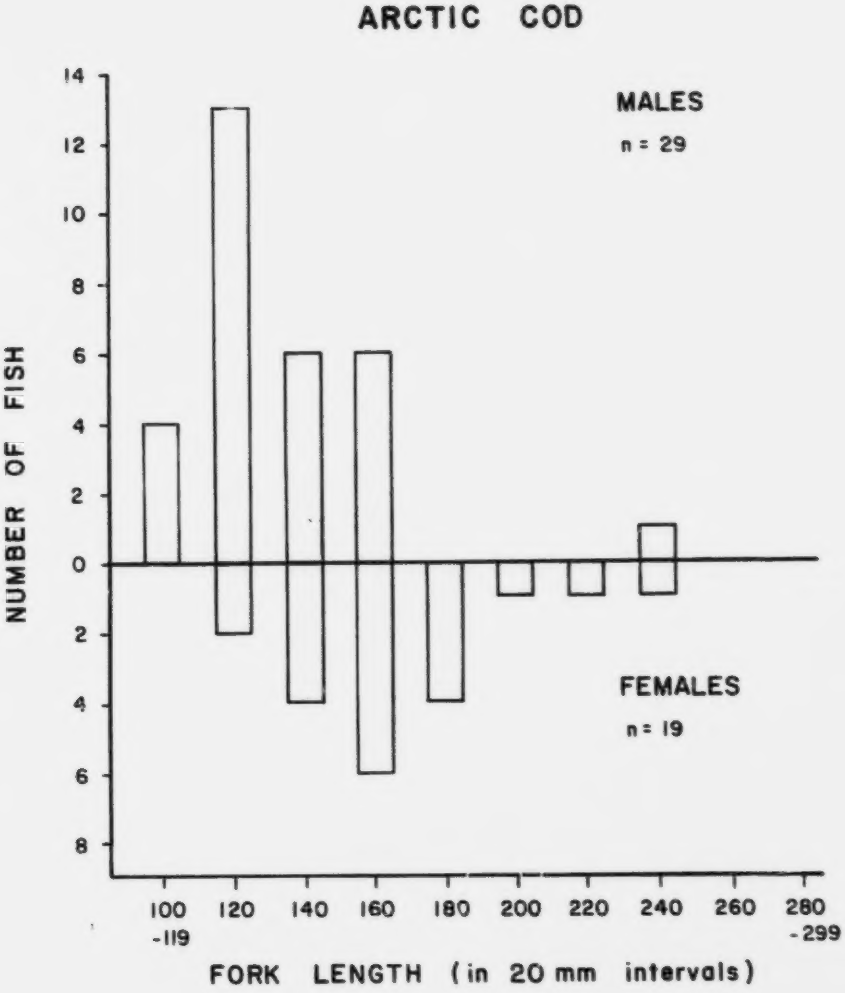

Figure 54. Size composition of sexually mature arctic cod.

spawned-out females and 12 spawned-out males were collected under the ice. On the final winter sampling trip (30 April-12 May 1979), another spawned-out female was taken.

Fish judged to be potential spawners were distributed throughout the study area in November (Fig. 7, Table 11), but all ripe (n = 1) and spawned-out (n = 18) cod taken later in the winter were in Stefansson Sound. In general, few arctic cod (spawning or otherwise) were collected at sites other than Stefansson Sound in February and May. The catch per unit effort (CPUE) for this species at principal winter sampling locations was (Table 11):

	CPUE (fish per 24-h gill or fyke net set)			
Date	Thetis Island	Simpson Lagoon	Stefansson Sound	Narwhal Island
November	0.5	0.9	0.7	0.5
February	0	0	3.8*	0
May	0	0*	0.4*	0.5*

*fyke net

The apparent concentration of arctic cod in Stefansson Sound may be an artifact of sampling techniques. In February all cod were caught in fyke nets which were used only at Stefansson Sound. Gill nets apparently did not catch cod after spawning.

The relative importance of nearshore sites compared to regions farther offshore for spawning by arctic cod remains unknown.

Food Habits. Major food items of arctic cod in nearshore waters are mysids (*Mysis litoralis*, *M. relicta*), amphipods (*Onisimus glacialis*) and copepods (Table 39). The dietary importance of these groups varied considerably between years--each was a major and minor component at one time or another:

Prey	% Composition (range) in Diet
Mysis litoralis	5.6-67.0
Mysis relicta	8.2-35.5
Onisimus glacialis	0.4-34.5
copepods	0.4-44.0

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Table 39. Foods of arctic cod in summer (Simpson Lagoon) and winter (Thetis Island to Narwhal Island).

	% Composition (Wet Weight)			
	Summer			Winter
Food Item	1977	1978	1979	1978-79
MYSIDS				
Mysis litoralis	5.6	9.8	40.1	57.0
Mysis relicta	35.5	26.9	19.3	8.2
Remnants	47.0	1.5	*	28.0
AMPHIPODS				
Apherusa glacialis	-	-	0.6	-
Haliragés mixtus	-	-	*	0.1
Onisimus glacialis	6.6	12.3	34.5	0.4
Gammarus setosus	0.1	-	2.6	-
Parathemisto spp.	1.7	-	-	-
Pontoporeia affinis	0.2	0.2	0.5	0.2
Pontoporeia femorata	-	-	*	0.1
Gammarocanthus loricatus	0.4	-	0.1	*
Remnants	0.5	5.3	0.9	2.2
COPEPODS	2.1	44.0	0.9	0.4
CUMACEA	-	-	*	*
EUPHAUSIID	0.5	-	0.4	-
FISH	-	-	-	1.5
FREE EGGS	-	-	-	*
MISCELLANEOUS SPP.	*	-	-	1.9
No. Stomachs Examined	34	20	47	84
Mean Size Fish (mm)	160	109	92	125

*< 0.1%

As described in 'Feeding Ecology', this variability yielded moderately low index values for dietary overlap between years of study.

Saffron Cod

The Beaufort Sea is the northern limit of distribution for the saffron cod (*Eleginus gracilis*). These fish are widespread along the Beaufort coastline but not generally abundant. Small numbers have been caught in Prudhoe Bay (Bendock 1977), along the Yukon coast (McAllister 1962; Kendel et al. 1975), in the Mackenzie Delta (Percy 1975) and along the Tuktoyaktuk Peninsula (Jones and Den Beste 1977). Saffron cod are occasionally important food items for birds and mammals (Percy 1975; Lowry et al. 1978; Springer and Roseneau 1978).

The occurrence of saffron cod in Simpson Lagoon was variable. None was caught in 1977, but 463 were taken the following summer. A few were also caught in winter at Thetis Island (n = 36), in the Colville Delta (n = 1) and in Simpson Lagoon (n = 1) (Table 11).

Most saffron cod caught were small fish of lengths 80-220 mm (Fig. 55). Considerably larger saffron cod have been taken at other Beaufort Sea locations: 300-413 mm at Tuft Point (Jones and Den Beste 1977), 310-450 mm in the Mackenzie Delta (Percy 1975). Some of the size difference at various locations may be a reflection of the sampling gear used to catch the fish. The fyke nets used in Simpson Lagoon tend to collect smaller fish than the gill nets used at the other locations. However, gill nets were also used in Simpson Lagoon but no saffron cod were caught by this method.

Ages of the study population were determined by otoliths. A very clear pattern of annuli was obtained when the otoliths were broken in half and lightly burned across the exposed edge. The saffron cod in Simpson Lagoon were all young fish, principally ages 1 and 2:

		Fork Length (mm)		
Age	n	$\bar{x}$	Range	S.D.
1	108	125	79-192	21
2	69	198	145-242	21
3	1	247	-	-
4	3	256	200-303	52

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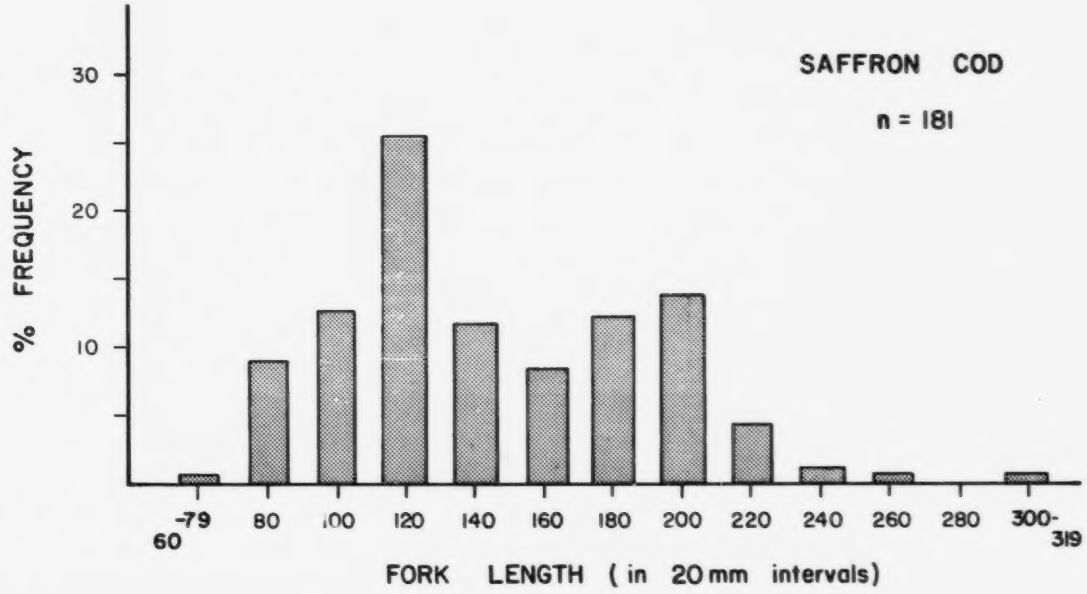

Figure 55. Length frequencies of saffron cod caught by fyke net in Simpson Lagoon, open-water season 1978.

The growth rate of these fish is generally similar to that reported for the young of this species in Siberia (Andriyashev 1954).

The length-weight relationship for the study sample (n = 180, r = 0.94, size range = 79-305 mm) is as follows:

$$\text{Log Weight (g)} = -5.610 + 3.233 \text{ Log Length (mm)}$$

The state of maturity was difficult to assess because of the limited size range and the youth of fish in Simpson Lagoon. There were indications that a few males might spawn in the year of capture. Testes in these fish appeared well developed in September when the ratio gonad:body weight exceeded 10% in 12 of 41 males. Egg diameters of females caught in late August were as large as 0.4-0.6 mm; these sizes confirm neither maturity nor immaturity at this time of year.

Kotzebue Sample. Since the biology of saffron cod is not well known, we took advantage of a sample of this species collected outside our study area. The sample was part of a subsistence catch of "tomcod" jigged through the ice just offshore from the village of Kotzebue, Southeast Chukchi Sea, on 15-30 November 1978).

The sample consisted almost entirely of large, mature fish that were approaching a spawning condition. The average fork length was 238 mm (n = 33, SD = 17, range = 207-283 mm). Most were females (79%) and all but one of each sex were mature. Egg diameters of females averaged 0.9 mm (n = 11, SD = 0.16, range = 0.6-1.1 mm).

Only three fish (9%) in the Kotzebue sample had empty stomachs; the rest had eaten fish, mysids and decapods:

Food	% Wet Weight
fish	68
mysids	
Neomysis rayii	15
miscellaneous	3
decapods	13

Broad Whitefish

Anadromous broad whitefish (*Coregonus nasus*) are common in summer along the coastline near the mouths of larger rivers such as the Colville, Sagavanirktok and Canning (Kogl 1972; Kogl and Schell 1974; Craig 1977; Bendock 1977); however, they were not particularly abundant in Simpson Lagoon in 1977 or 1978 (Table 4).

In the study area, sizes of broad whitefish captured varied according to sampling gear used (Fig. 56). The size range, 66-548 mm, was bimodal with all fish in the 60-200 mm or 260-520 mm size groups. Similar data were obtained for this species caught the previous two years in Prudhoe Bay (Bendock 1977). It is not known why medium-size fish were either absent or not caught in these coastal waters.

Broad whitefish in Simpson Lagoon are long-lived, slow-growing and late-maturing (Table 40). They ranged in age from 1-22 years and appeared to reach sexual maturity between ages 9 and 14. Most of the broad whitefish in coastal waters were immature fish (51%) or mature non-spawners (36%), but a few mature green fish (13%) were also present. The latter were females whose egg sizes indicated they would spawn in the fall (Fig. 57). For comparison, egg sizes of two mature green females caught during our surveys in the lower Colville River at Ocean Point were 1.9 and 2.1 mm on 21 August 1978. Spawning time for Mackenzie River fish is in October (Jessop et al. 1974).

All males in coastal waters were immatures or mature non-spawners. This is especially evident when the ratio of testes:body weight of the coastal fish is compared to that of five mature green fish caught in the Colville River at Ocean Point and near the Anuktuvik River on 21 August 1978 (Fig. 57).

In general, data regarding the reproductive cycle of anadromous broad whitefish are sparse, but the Simpson Lagoon data we have presented are in basic agreement with the information obtained at other Beaufort Sea locations (de Graaf and Machniak 1977; Bendock 1977).

A length-weight regression for the coastal sample of broad whitefish is:

$$\text{Log Weight (g)} = -4.976 + 3.011 \text{ Log Length (mm)}$$
$$n = 65,\ r = 0.97$$

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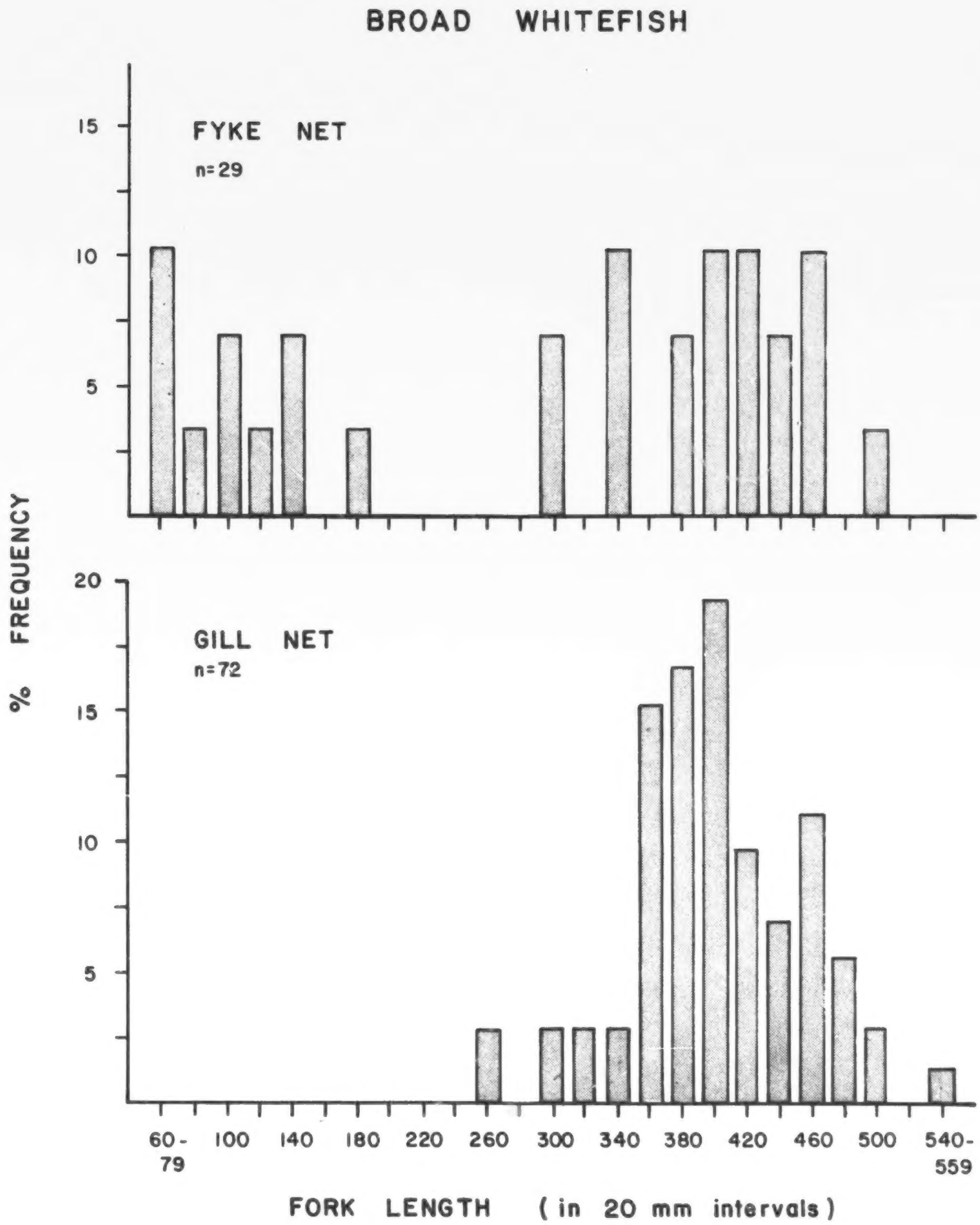

Figure 56. Length frequencies of broad whitefish caught by two methods in Simpson Lagoon, summer 1977 and 1978.

Table 40. Age-length relationship (otolith-based) and maturity of broad whitefish caught in Simpson Lagoon in summer, 1978.

		Fork Length (mm)			
Age	n	mean	(range)	SD	% Mature
1	2	114	(104-124)	14	0
2	5	141	(98-186)	34	0
3	0	-	-	-	-
4	0	-	-	-	-
5	0	-	-	-	-
6	2	332	(314-351)	26	0
7	3	330	(311-364)	30	0
8	0	-	-	-	-
9	3	378	(331-406)	41	33
10	6	376	(348-394)	16	17
11	6	414	(410-431)	9	50
12	4	422	(403-450)	21	50
13	0	-	-	-	-
14	5	468	(420-548)	48	100
15	3	446	(432-461)	15	100
16	2	438	(411-465)	38	100
17	3	453	(424-471)	26	100
18	0	-	-	-	-
19	0	-	-	-	-
20	0	-	-	-	-
21	2	478	(470-485)	11	100
22	1	466	-	-	100
Total	47				49%

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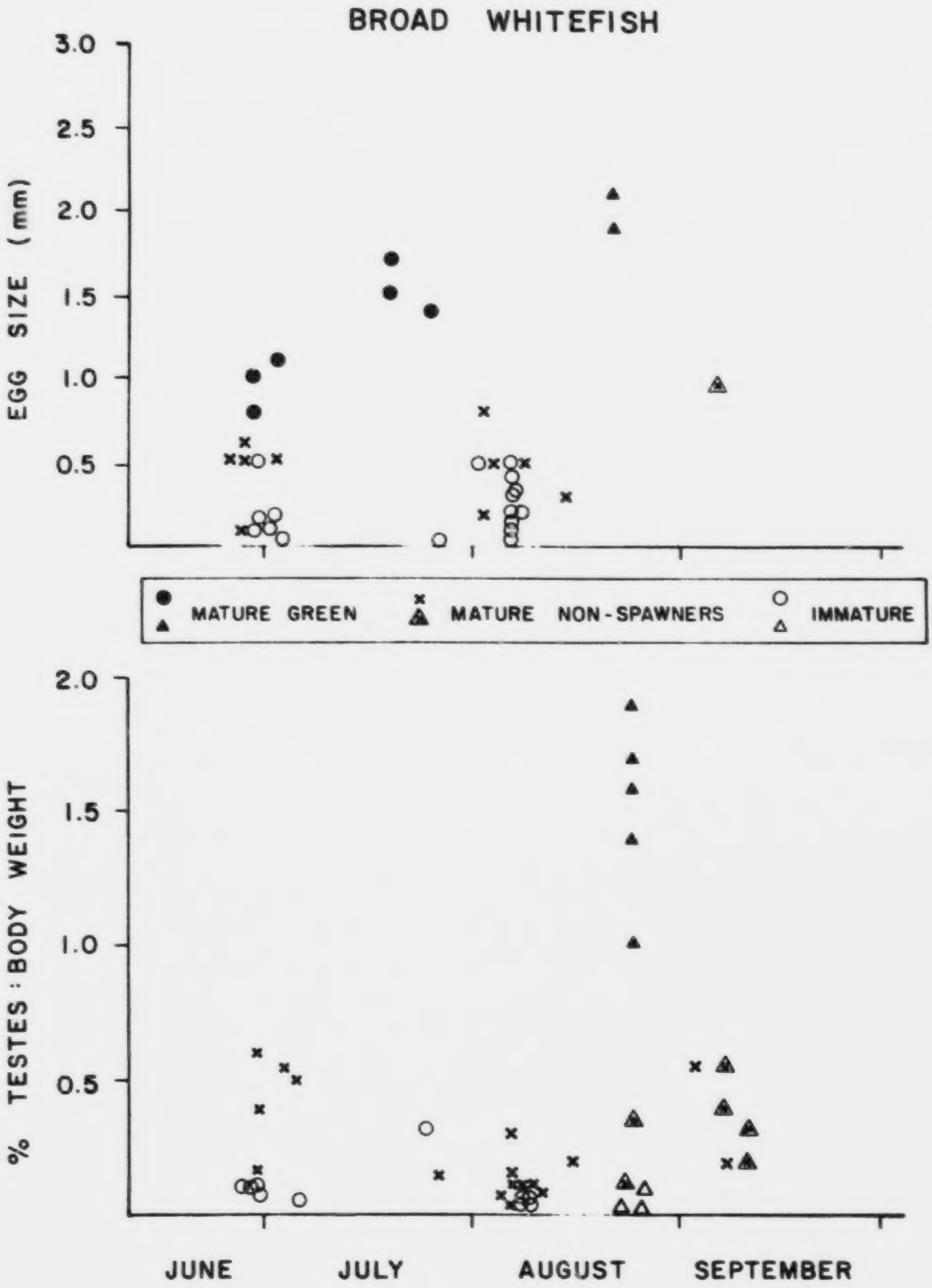

Figure 57. Seasonal changes in egg size and testes:body weight ratios of broad whitefish in the lower Colville River (triangles) and Simpson Lagoon (symbols other than triangles), 1978 and 1979. Only males > 200 mm long were used in these analyses since smaller immature males occasionally give erratically high values.

Humpback Whitefish

Relatively few anadromous humpback whitefish (*Coregonus clupeaformis*) were caught in Simpson Lagoon (Table 4). Those caught by gill net were large fish, 280-461 mm in length (Fig. 58). A few smaller fish may have been present, but none was caught by fyke net in 1977, and those caught in 1978 by fyke net (n = 73, 0.04% of total catch) were not measured. Bendock (1977) caught similar sizes of this species in Prudhoe Bay, 1975 and 1976.

A length-weight regression for the coastal sample of humpback whitefish is:

$$\text{Log Weight (g)} = -5.750 + 3.318 \text{ Log Length (mm)}$$
$$n = 41,\ r = 0.97$$

Arctic Flounder

The arctic flounder (*Liopsetta glacialis*) is a shallow-water flatfish which frequents brackish coastal waters. In Beaufort Sea waters, little is known about this species other than its nearshore distribution; relatively small catches have been taken at several locations between the Colville and Mackenzie Rivers. Bendock (1977) noted that their numbers were greater around the Colville River than in coastal waters farther east; our own data support this trend, since 578 were caught in Simpson Lagoon over two summers compared with only 37 over two summers in the Prudhoe Bay area (Bendock 1977). Low numbers of arctic flounders reported at other coastal sites may be a reflection of the sampling gear used. In our study, fyke nets caught virtually all flounders (98%) in our 1977 collection when both fyke and gill nets were used extensively.

Arctic flounders in Simpson Lagoon were 96-267 mm long (Fig. 58). Similar sizes of fish have been recorded at other coastal locations (Griffiths et al. 1975, 1977; Percy 1975; Kendel et al. 1975; Bendock 1977).

Principal foods of this species were identified by the Hynes Point method (Hynes 1950). Amphipods, mostly *Onisimus*, and isopods were the main prey in Simpson Lagoon:

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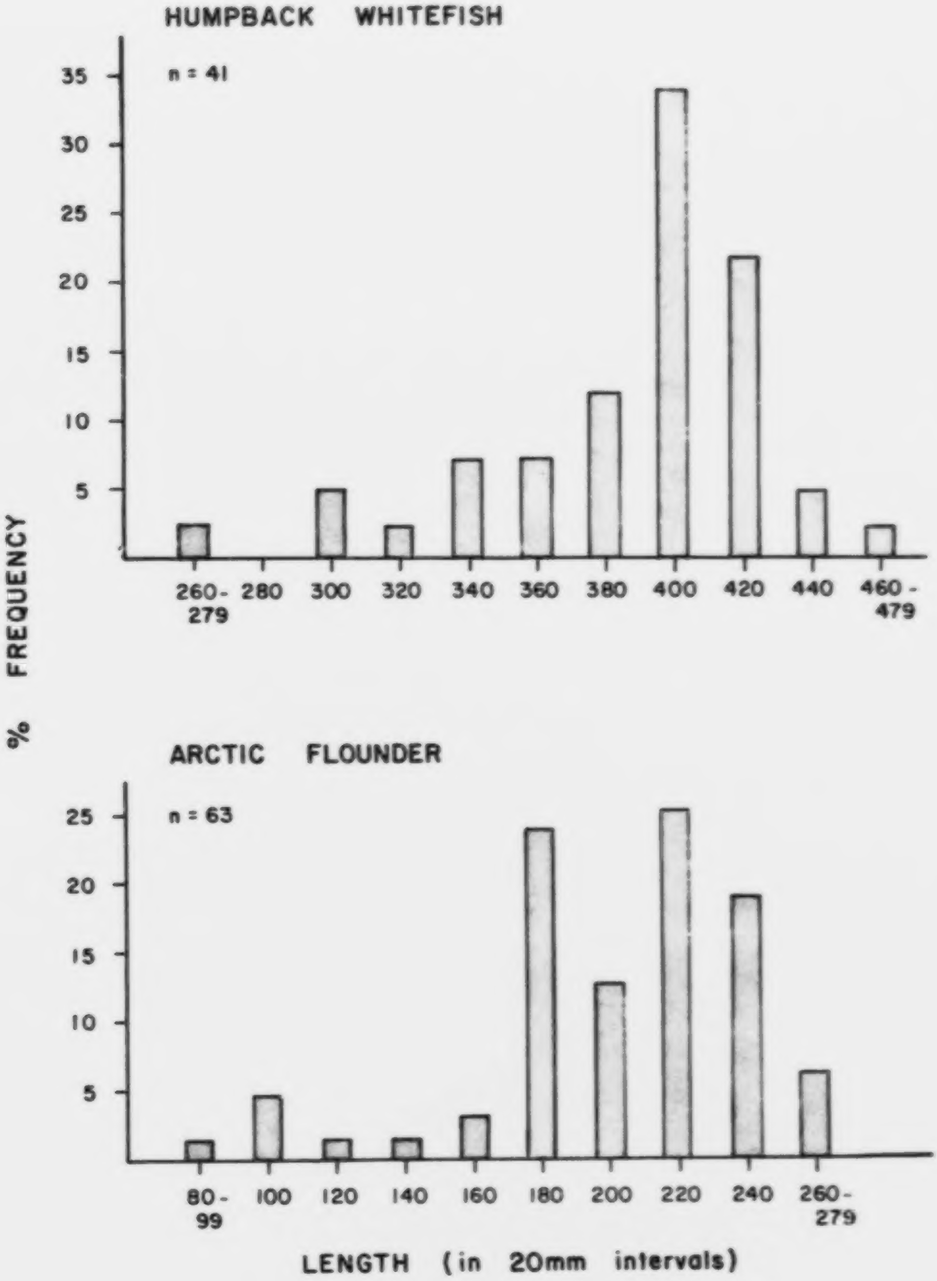

Figure 58. Length frequencies of humpback whitefish and arctic flounder caught in Simpson Lagoon, summer 1977 and 1978.

Food Item	% Composition (Hynes Point Method)
Amphipods	58
Isopods	30
Fish	7
Polychaetes	3
Mysids	1

No. Stomachs examined: 31
No. Empty: 15

Bendock (1977) obtained similar results in Prudhoe Bay, where the flounders ate primarily amphipods with some mysids and isopods.

Capelin

Capelin (*Mallotus villosus*) may migrate into shallow coastal waters of the Beaufort Sea to spawn in mid- to late summer. Their numbers are generally low, although large spawning runs occur occasionally. McAllister (1962) recorded such an event at Herschel Island in 1960.

Few capelin were caught in Simpson Lagoon in 1977 (n = 8) or 1978 (n = 58). They ranged in size from 109-137 mm (Fig. 59).

The capelin is probably the only species of fish that spawns in Simpson Lagoon. Ripe males and females were caught at Milne Point between 19 August and 1 September. At this time, egg sizes of females averaged 0.8 mm (range 0.6-1.0 mm; n = 13). Most of these fish had not recently fed (73% empty stomachs, n = 49).

Salmon

Salmon are not often abundant in Beaufort Sea waters. Relatively small populations of chum (*Oncorhynchus keta*) and pink salmon (*O. gorbuscha*) occur in the Mackenzie and Colville Rivers, and a few of these species occasionally enter other North Slope drainages such as the Sagavanirktok River.

No salmon were caught in Simpson Lagoon in 1977, but there was a run of pink salmon in 1978 (see 'Fish Movements'). The run occurred during 4-9 August 1978 when 87% of the total summer's catch of pink

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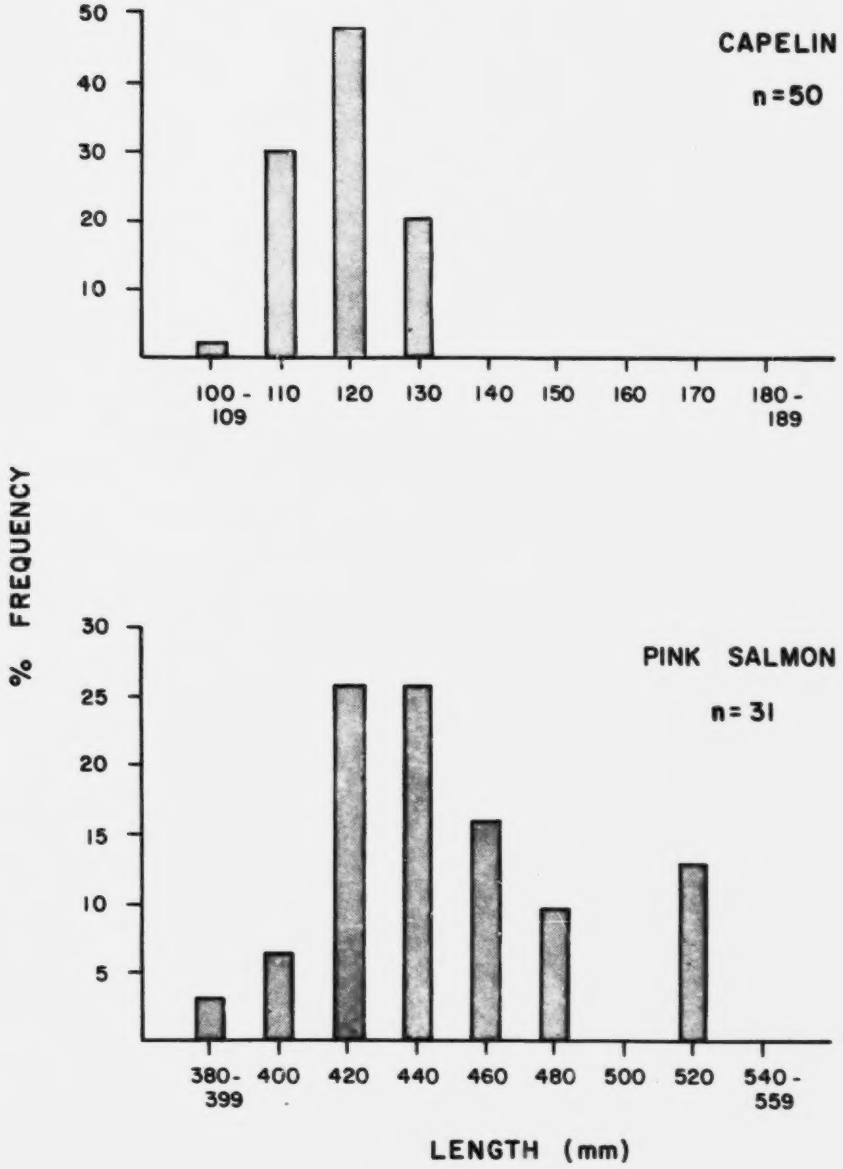

Figure 59. Length frequencies of capelin and pink salmon caught in Simpson Lagoon, summer 1978.

salmon (n = 166) were caught at Milne Point. These fish ranged from 388 to 540 mm in length (Fig. 59). Two pink salmon were also caught in the Colville River at Ocean Point on 21 August 1978.

Three other salmon species were caught in 1978. Two chum salmon, 600 and 622 mm in length, were caught in Simpson Lagoon; a chinook (king) was caught in the Colville Delta on 11 August 1978; and a 308 mm male sockeye (37 gill rakers) was caught in the Colville River about 1 km below the Anuktuvik River on 21 August 1978. Sockeye salmon have not previously been recorded in Beaufort Sea drainages.

Other Species

Grayling and round whitefish are occasionally caught in nearshore waters, especially when salinities are low. Five grayling and three round whitefish were collected at Milne and Kavearak Points when salinities were 1-9% (19-28 July 1979). Another round whitefish had ventured out as far as Pingok Island. Lengths of the round whitefish were 120-325 mm.

Other fishes caught in Simpson Lagoon during the summers of 1977-1979 were:

	n
ninespine stickleback	56
snailfish	10
Pacific herring	6
threespine stickleback	3
Pacific sand lance	1

Occurrences of the last two species represent apparent range extensions. The threespine stickleback had not been previously recorded in Beaufort Sea waters, and the Pacific sand lance had not been collected between the Chukchi Sea and Herschel Island, Yukon Territory (McAllister 1962; McPhail and Lindsay 1970; Hart 1973; Scott and Crossman 1973).

GENERAL DISCUSSION

The unifying theme of this report has been to examine the role of fishes in a barrier island-lagoon ecosystem of the Beaufort Sea. This examination has involved a diverse array of topics concerning habitat usage in summer and winter, trophic relationships, and often descriptive features since the life-cycles of some species are poorly understood. By identifying the biological significance of nearshore habitats to fish, we are in a better position to predict how fish may be affected by industrial developments in coastal waters. The following is a general review of arctic fish populations, their use of nearshore habitats, and factors that might affect these uses.

Characteristics of Arctic Fish Populations

Fishes in arctic environments are exposed to biotic and abiotic conditions that differ from those encountered in sub-arctic, temperate, and tropical environments. Compared to more southerly communities, arctic communities differ in having lower species diversities and reduced trophic complexities (e.g., Dunbar 1973; Quast and Hall 1974; McAllister 1977). Controlling abiotic conditions are extreme in arctic ecosystems, where fishes must cope with very cold temperatures and ice-covered waters. Arctic fishes have developed life-history, behavioral, physiological, and population characteristics that enable them to exist in these conditions (McAllister 1977), and assessments of impacts on arctic fish populations must consider these characteristics.

Arctic fish communities, like other arctic animal communities, have fewer species than their lower latitude counterparts. In the arctic marine environment, approximately 85-104 species are found in 23 families (Quast and Hall 1974; McAllister 1977). This is considerably lower than the 298 species and 40 families reported for the Bering Sea, or the 287 species and 55 families reported in the Gulf of Alaska (Quast and Hall 1974).

One method of examining life-history strategies of arctic fishes is to compare arctic species with ecologically and taxonomically similar species from sub-arctic or temperate ecosystems. Arctic char (*Salvelinus* *alpinus*) may be compared with its congener, Dolly Varden (*S. malma*) to provide some insight into life-history characteristics of arctic anadromous species. Table 41 summarizes the available information in important life-history characteristics for the two species.

Arctic char and Dolly Varden differ markedly in reproductive biology and age-growth patterns. The arctic species becomes sexually mature at a much later age than does the temperate species; also, it skips one or two years between spawning episodes. The arctic char also tends to grow slower and live longer than the Dolly Varden. Several authors (Murphy 1968; Wilbur et al. 1974) contend that species that exhibit reproductive potential over many years (iteroparity), as observed in the arctic fishes, have an advantage when the survival rate of prespawners is uncertain; harsh or fluctuating environmental conditions occasionally cause high mortality of eggs or juveniles. Craig and McCart (1976) discussing the survival advantages of the reproductive strategies of arctic anadromous fishes, note that these fishes

> '...are to some extent adapted to withstand at least short-term fluctuations in the environment, natural or man-made (e.g., Johnson 1972). As a result of the great longevity, long period of maturity, and the habit of repeat spawning, there is a great variation in the ages of fish spawning in any single year. This overlap means that populations are not dependent on the survival of any single year-class ... An additional factor ensuring population survival is the fact that for many anadromous species, there are major differences in the migration patterns of various life-history stages, so that an entire population may not be concentrated in a single locality during the course of the year. This reduces the possibility that an entire population can be destroyed by a single, localized event.'

Less is known about most arctic marine fish species, and, as a result, finding suitable comparable arctic and non-arctic species within this group is not as easy as it is for the anadromous species. In Table 41, life-history data for arctic cod are compared to similar data for the Atlantic cod, the Greenland cod and the Pacific cod. It is immediately apparent that species differences in this case are almost the opposite of those found in the anadromous species pair. The arctic

Table 41. Growth and reproductive comparisons between some arctic and sub-arctic fishes. Fish species: Dolly Varden (*Salvelinus malma*), arctic char (*S. alpinus*), arctic cod (*Boreogadus saida*), Atlantic cod (*Gadus morhua*), Greenland cod (*G. ogac*), Pacific cod (*G. macrocephalus*). Data sources: Leim and Scott 1966; Hart 1973; Scott and Crossman 1973; Moore and Moore 1974; Bain and Sekerak 1978; this study.

	Anadromous Fish			Marine Fish			
		Arctic Char					
	Dolly Varden	North Slope	High Arctic	Arctic Cod	Atlantic Cod	Greenland Cod	Pacific Cod
Maximum age	7-11	15	24+	6	16	11	13
Maximum size (cm)	62	63	82	23-38	71	64-102	76-89
Size at age 5 (cm)	25-46	30-34	11	21-30	44-52	-	54-61
Age at maturity	3-6	7-9	10-13	2-3	3-4	5-6	5
Annual spawning	yes	no	no				
Fecundity (x 10^3)	1.3-3.4	3.2-3.9	2.2-3.5				
(x 10^6)				0.01	-	1-9	2-6

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marine species matures sexually at an earlier age than its sub-arctic counterparts, it has a shorter life span, and it achieves a much smaller maximum size. As expected, the fecundity of the relatively small arctic cod is much less than the larger *Gadus* species.

It is clear that, at least in this example, the arctic marine species has a very different life-history strategy than the arctic anadromous species. Unfortunately, there are no other arctic-temperate pairs of marine species in which enough life-history information is available to corroborate or refute the trend seen in the cods. Arctic marine species tend to be small, and often arctic species do not reach sizes as large as their sub-arctic or temperate congeners. For example, the arctic fourhorn sculpin, *Myoxocephalus quadricornis*, reaches a maximum length of about 25-30 cm, while its north Atlantic congeners *M. octodecemspinosus* and *M. scorpius* have maximum lengths of 36-45 cm and 60-90 cm, respectively, and the north Pacific species *M. polyacanthocephalus* reaches a maximum size of 76 cm.

Fish Use of Nearshore Habitats

To put the fisheries importance of Simpson Lagoon into perspective, it is useful to compare the important biological activities of fish that occur in this habitat with those that occur elsewhere. Four broad categories of fish activity are (1) spawning, (2) feeding, (3) movements and migration, and (4) overwintering. The last category, though less an activity than a requirement for suitable habitat, represents an annually critical event in the lives of arctic freshwater and anadromous fish.

With minor qualifications, shallow coastal waters ($\leq$ 2.5 m) are used only for feeding and migrating by both anadromous (A) and marine (M) species:

	Nearshore Waters	
Activity	shallow (< 2.5 m)	deeper (> 2.5 m)
feeding	A, M	A*, M
migrating	A, M	A*, M
spawning		M
overwintering		M

*relatively uncommon except off mouths of large rivers.

One of the principal advantages of anadromy is that fish have access to the abundant food resources in the marine environment (McCart 1970; Craig and McCart 1976). The arctic anadromous fish obtain much of their annual food budget during their brief summer visit to coastal waters. These fish are also highly mobile once they reach coastal waters; although movements of individual fish are not known in detail, tagging data suggest that fish cruise along the coastline rather than remain in one area for a long time. Anadromous fish are distributed throughout nearshore waters, but are most abundant along shorelines, and greatest concentrations often occurred within 100 m of the mainland shore. There is no indication that this distribution is associated with particular substrate or vegetation types since shallow nearshore waters provide little diversity in this respect.

Our winter studies indicate that spawning and overwintering by anadromous species (except boreal smelt) do not occur in the marine environment in arctic Alaska. However, spawning and overwintering are indirectly tied to nearshore waters in that the food reserves acquired during the summer are probably essential to the reproductive success and overwintering survival of anadromous fish. It should be noted that overwintering in marine habitats does occur in other regions of the arctic where flow from very large rivers provides an underice plume of fresh water into the ocean (Berg 1957; Percy 1975).

Use of shallow waters by marine fishes (sculpin, cod) is basically similar to that described for anadromous fish, although there are some exceptions. Fourhorn sculpin are less mobile than anadromous species and they apparently may reside in one general region of the coastline for a long period of time. A more consequential difference is that marine fish may inhabit nearshore areas during early winter until increasing ice thicknesses force them into deeper waters.

Spawning and overwintering by marine species take place largely in deeper nearshore waters (> 2.5 m deep) and in offshore waters. The boreal smelt, an anadromous species, also overwinters in nearshore waters.

Implications of Feeding Ecology

Information derived from the fish and bird feeding studies supports the following conceptual view of community and trophic structure in Simpson Lagoon, and suggests how petroleum-related activities may affect fish, birds and their prey.

Food Supplies

Several lines of evidence indicate that there is a superabundance of food available to fish and birds during the summer period. Invertebrate studies in the lagoon show that roughly 10-50 times more food (mysids and amphipods) is available than is required daily by all vertebrate consumers in the system (Griffiths and Dillinger 1980). This relatively high level of food is maintained through the open-water period. During summer, it is also generally accessible to predators because the prey is epibenthic in habit (as opposed to infaunal) and the lagoon bottom provides little structural diversity (e.g., rock crevices or vegetated areas) for refuge from predation, although some prey may escape into the detrital mat on the lagoon bottom. Furthermore, this high level of food abundance is not restricted to the lagoon environment itself but also occurs in the relatively shallow marine environment seaward of the lagoon (Griffiths and Dillinger 1980).

The high diet overlap among consumers is also a strong indication that food is superabundant. Overlap is not simply a reflection of a reduced variety of species in the arctic, for there are several sources of food in the lagoon which predators do not appreciably exploit. Few vertebrates eat molluscs, polychaetes, isopods, tunicates or hydroids, yet these groups comprise a large proportion of the potential supply of food in Simpson Lagoon. Instead, consumers feed primarily on the abundant epibenthic invertebrates and there is a high degree of overlap among consumer diets. Because the available food supply is not finely partitioned by the predators, the implication is that, in general, there is a lack of competition for food in the nearshore environment. If the food resources had been in limited supply, general ecological theory (Competitive Exclusion Principle) holds that competition for food would be high and therefore we should observe specialized and non-overlapping feeding habits among predators. There are no reasons to suspect that the high food levels observed during the 1977 and 1978 open-water seasons were unusual events.

Some exceptions to this generalized pattern of diet overlap occur. Fourhorn sculpin, for example, eat more isopods than other consumers, and boreal smelt eat more fish. Differences in the sizes, shapes and positions of fish mouths of different species also indicates a degree of feeding specialization among nearshore fishes. Despite these differences, the epibenthic food resource remains the principal diet of most fishes.

Some consumers also display differences in feeding habitat preferences. However, recognition of this partial partitioning of lagoon habitat should not obscure the point that the lagoon's supply of epibenthos (especially mysids) is highly dependent on immigration or dispersal from outside areas (Griffiths and Dillinger 1980). Thus, both the oldsquaw ducks (which feed mainly in open lagoon waters) and fish (which probably feed near shorelines) are feeding on the same food supply but at different points along its pathway through the lagoon.

Can the premise that food is superabundant be extrapolated to other nearshore areas along the Beaufort Sea coastline? The available data suggest that the kinds of fish using Simpson Lagoon are generally similar to those all along the Beaufort Sea coastline, and at all locations studied the fish rely on epibenthic invertebrates as their principal food resource (e.g., Kendel et al. 1975; Furniss 1975; Griffiths et al. 1975, 1977; Bendock 1977). However, it is premature to extrapolate the 'food superabundance' premise to other localities or even other years. In August 1978, an event occurred in Simpson Lagoon which suggested that fish may, on occasion, reduce the food supply to low levels. The event was the brief entry into the lagoon of a large school of arctic cod (see 'Fish Movements'). They consumed a large quantity of mysids during their nine-day visit and this may have contributed to a decline in mysid densities at this time (Griffiths and Dillinger 1980). This decline did not substantially affect the food base, but it is conceivable that the large school of cod, given its estimated size and food consumption rate, could have seriously depleted the lagoon's food supply if it had remained in the lagoon an extra two weeks or so.

A second note of caution is that a high incidence of empty fish stomachs has been recorded at some coastal locations (Table 42). While the occurrence of empty stomachs may reflect a number of factors (e.g., diel periodicity in feeding, regurgitation of digestion of food after fish capture, reduced feeding for anadromous fish on return migration to fresh water), the data also are consistent with either of two very different interpretations: (1) fish may not have to feed continuously in order to satisfy their nutritive requirements, or (2) fish are not getting enough to eat at some locations or in some years.

Factors Contributing to Food Abundance

Immigration. Despite the large standing stocks of epibenthos in Simpson Lagoon in summer, birds and fish could theoretically consume the entire stock within 2-6 weeks (Griffiths and Dillinger 1980). But a steady decline of food does not occur--the food supply is maintained at its relatively high level throughout the summer, despite an increase in consumer demand as the summer progresses. Potential reasons are (1) growth of the invertebrates present in the lagoon and/or (2) immigration of new invertebrates into the lagoon. Reproduction does not occur during summer. Griffiths and Dillinger (1980) show that the factor (2) is probably the more important. *Mysis litoralis*, the major prey species, moves into the lagoon in early summer; this 'inoculation' and the continuing immigrations that follow, are critical events for the fish and birds. Thus, we see that shallow nearshore habitats become 'food rich' only after being repopulated each year by key invertebrates and remain food rich only by continued immigration. If these immigrations are obstructed by either natural events or man-caused structural alterations in the nearshore environment, the lagoon might remain a poor feeding area for that particular summer.

Productivity in Simpson Lagoon is, perhaps, linked to offshore areas in even a more fundamental way. Preliminary isotopic studies of organisms collected in the lagoon indicate that fish ultimately obtain

Table 42. Proportion of empty stomachs from fish collected at several locations in Beaufort Sea coastal waters.

Location	Time	Arctic Cisco % (n)	Least Cisco % (n)	Arctic Char % (n)	Fourhorn Sculpin % (n)	Arctic Cod % (n)	Arctic Flounder % (n)	Boreal Smelt % (n)	Saffron Cod % (n)	Reference
Yukon Coast	June-Aug. 1973	15 (41)	13 (259)	22 (36)	11 (37)	-	-	-	-	Craig & Mann 1974 + unpublished data
Alaska Coast	July-Aug. 1973	0 (30)	0 (20)	20 (95)	5 (22)	-	-	-	-	
Nunaluk Lagoon	June-Sept. 1974	25 (344)	6 (34)	33 (206)	17 (314)	-	47 (19)	-	-	Griffiths et al. 1975
Prudhoe Bay	July-Aug. 1974	26 (53)	24 (70)	27 (52)	20 (10)	-	-	-	-	Furniss 1975
Kaktovik Lagoon	July-Sept. 1975	5 (301)	5 (21)	4 (137)	20 (275)	-	-	-	-	Griffiths et al. 1977
Simpson Lagoon	July-Sept. 1977	10 (326)	17 (94)	6 (114)	10 (220)	6 (90)	48 (31)	-	-	This study
Colville Delta	Apr.-May 1978	5 (64)	2 (42)	-	0 (10)	-	-	-	-	This study
Simpson Lagoon	July-Sept. 1978	27 (190)	19 (118)	34 (38)	-	8 (133)	-	55 (31)	6 (33)	This study
Alaska Coast	Nov.-Apr. 1978-79	-	-	-	26 (110)	7 (104)	-	59 (170)	6 (35)	This study

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60-70% of the carbon in their tissues from modern marine primary production--ice algae and phytoplankton (Schell 1979). Relatively little of the large input of terrestrially-derived organic carbon appears to enter trophic pathways leading to fish. This finding underscores the importance of the relationships between the lagoon and outside marine waters.

Seasonally Limited Availability. A factor that contributes to the abundance of epibenthos is that these invertebrates are not accessible to most vertebrate consumers for almost nine months of the year. Birds and anadromous fish have the opportunity to eat them only during the short open-water period. Marine fish, however, have almost year-round access to the epibenthos, although not in shallow lagoon waters.

Habitat Disturbance. Ecological succession, the orderly process of community change, is maintained at an early stage in Simpson Lagoon. The lagoon is a 'pioneer community' because periodic physical disturbance permits only a few invertebrate species to occur as permanent residents. Several features of the lagoon make life difficult. The lagoon is essentially a shallow, wind-churned and turbid channel of water. Its nearly featureless bottom is covered with an unstable mud-sand substrate--an environment that typically supports a low diversity of organisms. Summertime water temperatures and salinities are highly variable and a rapid flushing rate insures that the system is influenced by events outside its borders. In winter, portions of the lagoon freeze solid and little free water remains under the ice elsewhere; at this time water may become hypersaline. In springtime, there may be some ice-gouging of substrates as well as rapid and extreme fluctuations in salinity. All in all, the lagoon requires that organisms cope with fluctuating physical conditions on both daily and seasonal bases.

Species diversity in early successional stages is typically low but those species present are often represented by very large numbers. In Simpson Lagoon, it appears that the numerical success of the epibenthic invertebrates may be attributed to their mobile life style and tolerance of a wide range of physical conditions. Mobility is an essential asset; it allows mysids and amphipods to repopulate annually the nearshore that freezes solid each winter. These invertebrates are widespread and seem to utilize virtually the entire nearshore zone. They are tolerant of the wide ranges of water temperature and salinity (Busdosh and Atlas 1975; Broad et al. 1979) that occur in the nearshore environment, and some are even moderately tolerant of oil contamination at least on a short-term basis (Foy 1978, 1979). As a generalization, the epibenthic invertebrates share attributes with 'colonizing species', i.e., those species that are characteristically the first occupants in recently disrupted habitats. Williams (1969) describes colonizers as 'versatile species-creatures of the ecotone, physiologically and ecologically tolerant of many conditions and requiring of few'.

The contention that Simpson Lagoon is a 'disrupted' environment due to widely fluctuating physical conditions is reflected by the high degree of food overlap among consumers. As natural (or human) disturbance to an ecosystem increases, the amount of dietary overlap also increases (Tyler 1978). Tyler found that overlap is low in systems that are physically constant, i.e., systems with relatively little physical disturbance or fluctuation. In Dease Strait, a deep-water arctic area with year-round constant temperatures and almost year-round ice-cover, the assemblage of fishes has a very strong partitioning of food resources (low overlap). In contrast, fishes from physically disturbed habitats tend to have a weak partitioning of food resources (high overlap). This relationship is shown in Fig. 60. Tyler suggests that regularly repeated perturbations to a system would allow the persistence of high turn-over r-type species (Gadgil and Solbrig 1972) in abundance, accompanied by weakening of food resource partitioning and co-existence of predators that would otherwise not be possible.

To compare the Simpson Lagoon data with Tyler's findings, the percent overlap was calculated from principal prey diagrams (Fig. 28) since this was the method used by Tyler (1978). For the summer of 1977, there are 7 entries of principal prey (R rows) and 6 consumers (C columns). The possible number of reoccurrences of principal prey in consumer diets is R x (C - 1) or 35. Since there are 11 actual reoccurrences, the overlap was 11/35 = 31%. There was a 50% overlap the following summer. Analyzed in this fashion, the Simpson Lagoon data fall into the

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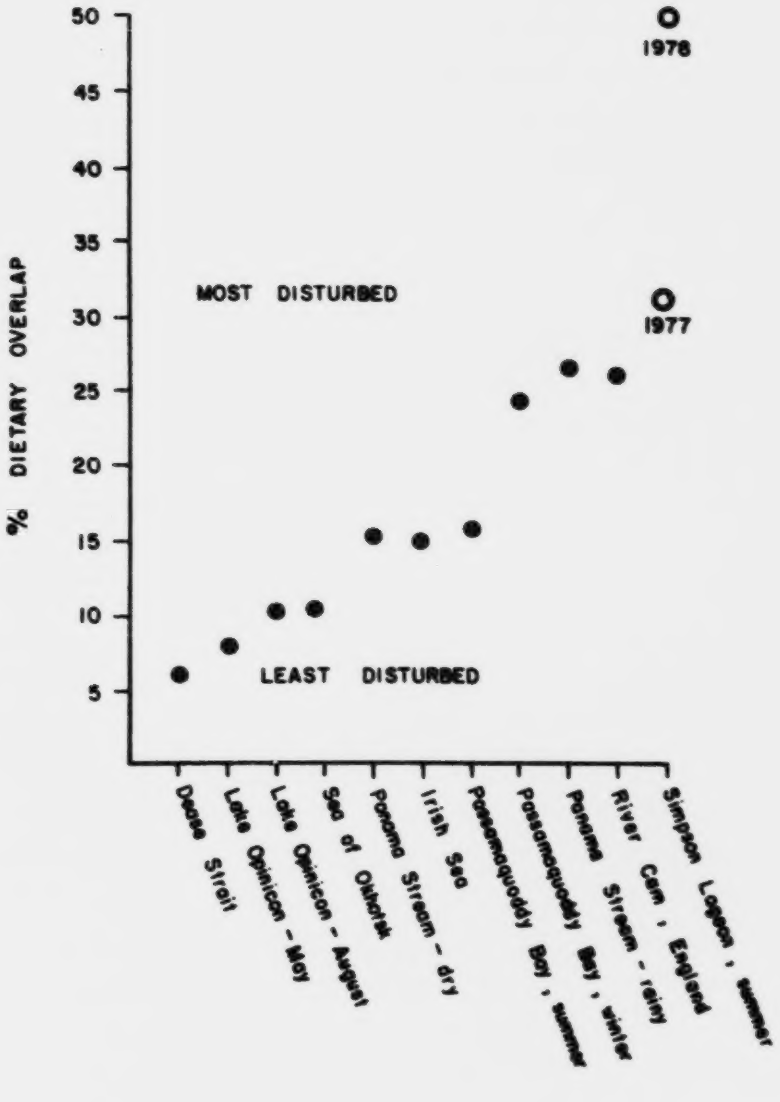

Figure 60. Relationship between dietary overlap among vertebrate consumers and the degree of habitat disturbance in the system (Tyler 1978). Data are ranked by percentage overlap; solid dots indicate overlap among fish communities at various locations, and open circles indicate overlap among major consumers (fish and birds) in Simpson Lagoon, summers 1977 and 1978. Redrawn from Tyler (1978).

category of 'most disturbed' habitats during the summer months (Fig. 60).

In winter, one might predict that overlap would be low since ice-cover would presumably dampen physical fluctuations; however, the widely separated overlap values obtained at different places and times during this period make interpretation difficult. Overlap was low in coastal waters (10%, 1978-79 winter) but high in the Colville Delta (50%, 1977-78 winter). Reasons for this difference are not known but may reflect several factors (e.g., different fish species, different habitats, small sample sizes). In any case, it is interesting that the low overlap in coastal waters for winter-caught marine fish is similar to that obtained by Tyler for summer-caught marine fish from deeper arctic waters.

In summary, it would appear from several different viewpoints that Simpson Lagoon is a rigorous habitat due to fluctuating physical factors (substrate, gouging and resuspension, turbidity, salinity and periodic freezing). This, in turn, suggests that--at least in summer--the few species successfully tolerating these conditions would not be overly sensitive to related types of small-scale perturbations to the physical environment which might result from petroleum-related activities.

Factors Influencing Fish Activities

In previous sections, we identified the activities of fish that occur in nearshore waters (feeding, migration, spawning, overwintering). Certain characteristics of the nearshore marine environment are undoubtedly critical to these activities, while others are perhaps of lesser importance to their successful completion. In an attempt to assess possible impacts of oil-related development on nearshore fish activities, it is necessary to evaluate which activities are most vulnerable to disturbance. In the following sections, we discuss the implications of our findings, and, where data are lacking, evidence from studies conducted in other locations or on other species is examined.

Feeding and Growth

The process of finding and capturing prey and incorporating it into biomass is a primary activity of fishes in the shallow nearshore arctic environment. While this aspect of fish biology is obviously dependent on the presence of adequate densities of suitable prey organisms, successful energy incorporation depends on factors besides food availability. First, the ability of fish to locate prey efficiently may depend on visibility (turbidity). Second, ingested food must be converted to usable and, in the case of many arctic species, storeable energy. The ability to do this requires efficient physiological mechanisms, which in fishes are in turn dependent on physical environmental conditions such as temperature and salinity.

Temperature has been shown to be an especially important factor in all aspects of fish energy budgets. Temperature influences the amount of food ingested (Kinne 1960; Brett and Higgs 1970), the rate at which food is digested in the gut (e.g., Brocksen and Bugge 1974; Jobling et al. 1977), and the general metabolic rate (e.g., Beamish 1964; Dwyer and Kramer 1975). In general, each of these variables increases with increasing temperature up to some level. Salinity also affects metabolism in fishes; in euryhaline species, the lowest rate of oxygen consumption (metabolism) usually occurs in brackish water at salinities near the fish's iso-osmotic point (e.g., Rao 1968; Hettler 1976).

Perhaps the best indicator of optimal physical conditions is growth rate. This characteristic integrates a broad spectrum of individual processes and should provide the most reliable measure of the combined effects of factors such as temperature and salinity.

There is extensive evidence that temperature has a large effect on fish growth rates (see Brett 1956, 1970; Kinne 1963). In all fishes studied, growth rate-temperature relationships follow a consistent pattern: as the temperature increases from lower limits of the tolerance range, the growth rate increases until an optimum temperature of most rapid growth is reached; above this level, a moderate or sharp decrease in growth occurs and some species exhibit negative growth (weight loss). This relationship is unlike the rate changes of specific physiologic processes such as digestion or respiration, which may increase continuously up to lethal temperatures.

A prevailing concern in temperature studies is the value of preference data. Growth studies are more meaningful in determining potential impacts of alterations to thermal conditions, but they are much more difficult to perform. It is of interest, therefore, to compare results of growth and preference studies where both types of information are available for the same species. Table 43 summarizes such data for ten species. It is apparent that preferred temperatures generally do approximate growth optima.

Salinity levels must also affect growth and, consistent with observations of metabolic optima, maximum growth in euryhaline fishes occurs at intermediate salinities near iso-osmotic levels (Otwell and Merringer 1975; Hettler 1976). Temperature, however, has been identified as having more effect on growth than does salinity (Otwell and Merringer 1975; Peters et al. 1976), although salinity changes may alter the optimum growth temperature (Kinne 1960).

Of specific concern in the Beaufort Sea is the importance of the band of warmer, less saline water that occurs immediately adjacent to the coastline and inside the barrier islands. Data indicate a strong correlation between the presence of this water and anadromous fish. Summer is a period of intense feeding activity for these fish, and they increase their stores of body fat and presumably accomplish much of their year's growth during summer. The availability of the warmer brackish water may be crucial to these fish if it enables them to grow at a faster rate than would be possible in the colder surrounding water.

In the available literature, every measure of a fish's well-being, such as digestion rate, respiration and growth, decreases rapidly as the temperature drops below 10°C, and decreases most sharply in the range around 5°C or lower. These observations suggest that there are physiological advantages to occupying warmer water, especially during a season of high food availability when alternative temperature regimes are near 0°C. It must be noted, however, that many fish species occupy habitats that are continually near 0°C, yet they grow and reproduce.

Table 43. Comparison of temperatures preferred by various fish species with temperatures optimal for growth.

Species	Life Stage	Optimal Growth Temp. (°C)	Selected Temp. (°C)	Reference
Sockeye salmon	young	15		Brett et al. 1969
Oncorhynchus nerka	young		14.5	Brett 1952
Brook Trout	young	12.4-15.4		McCormick et al. 1972
Salvelinus fontinalis	young		16	Peterson 1973
	adult		14.8	Spigarelli 1975
Emerald shiner	young	28.9		McCormick and Kleiner 1976
Notropis atherinoides	young		22-23	Barans and Tubb 1973
Yellow perch	young	22		Huh et al. 1976
Perca flavescens	young		22.5-23.3	Neil and Magnuson 1974
Walleye	young	22		Huh et al. 1976
Stizostedion vitreum	adult		20.6	Hile and Juday 1941
			23.6	Dendy 1948
Largemouth bass	fry	27.5-30		Strawn 1961
Micropterus salmoides	sub-adult	26-28		Coutant and Cox 1976
			29	Neil and Magnuson 1974
Smallmouth bass	juvenile	26		Horning and Pearson 1973
Micropterus dolomieui	spring young		19-24	Barans and Tubb 1973
	winter young		18	Barans and Tubb 1973
Bluegill sunfish	young	30		Lemke 1977
Lepomis macrochirus	young		31.2	Beitinger 1974
			29.4-31.6	Neil and Magnuson 1974
Pupfish	adult	30		Kinne 1960
Cyprinodon macularius	adult		35.5-36.5	Barlow 1958
Channel catfish	fingerling	30		Andrews and Stickney 1972
Ictalurus punctatus	adult	30	25.2	Reutter and Herdendorf 1975
	adult		30.5	Cherry et al. 1975

Unfortunately, there appear to be no studies on temperature preference or on temperature effects on physiological processes or growth in species that occupy very cold water during all or part of their lives. Swift (1964) did a growth study on arctic char (*Salvelinus alpinus*) from an isolated lake in England and found a growth optimum at 12-16°C; however, that population probably had adapted to prevailing temperatures that were presumably warmer than in the arctic. Thus, it is uncertain that, in arctic species, as sharp an increase in metabolic processes would occur above 5°C as occurs in temperate species.

Until preference studies or, preferably, growth studies have been done on the anadromous species in question, the importance of the warmer nearshore water to their well-being will remain questionable. However, the importance of temperature effects on growth in other fish species, and the correlation of selected temperatures and growth optima, suggests that these fish are gaining a real benefit from their selection of the warmer part of the nearshore environment. It does not seem unlikely that the availability of brackish or marine water above 5°C is important to these species.

Possible Developmental Effects. Industrial activities in nearshore waters may affect fish feeding and growth in two general ways. First, if the ability of fish to locate prey is dependent on visibility, then their feeding success may be affected by construction activities (e.g., dredging) which increase the turbidity of surrounding waters. However, the overall effect on fish feeding is probably localized and/or negligible since nearshore waters of the Beaufort Sea are frequently turbid due to wind-generated turbulence.

Second, solid-fill causeways may alter nearshore current patterns, and, consequently, change nearshore temperature and salinity regimes. For example, the Atlantic Richfield causeway in Prudhoe Bay deflects some westward-flowing brackish water away from the coastline and this water is replaced by colder, more saline water on the west side of the causeway (Mungall 1978). Assuming that warmer, less saline waters are indeed important to nearshore fishes, any large-scale change in nearshore temperatures and salinities may reduce their growth rate.

Migration

The presence of many anadromous fishes in the nearshore Beaufort Sea during the open-water season is an important feature of the arctic nearshore fish community. It is apparent from the winter sampling program that all of the anadromous species, with the exception of boreal smelt, leave marine water to overwinter in fresh or brackish river systems. Since few riverine habitats provide suitable spawning grounds or overwintering sanctuaries (many drainages freeze solid during the winter), this yearly movement requires accurate migrations by anadromous fishes. While the pattern of movements of anadromous fish in the study area is understood in a general sense, the behavioral or navigational mechanisms underlying these movements are not known (for example, see 'Effects of Physical Factors'). However, Beaufort Sea fishes probably have migratory habits or mechanisms that do not differ markedly from anadromous species in sub-arctic environments, and the recent use of ultrasonic tracking of individual fishes has resulted in some observations that may have general applications to fish migration. One general observation is that fish do not show highly oriented directional movement but tend to wander in many directions while sometimes attaining a net movement in one direction. This has been observed in Atlantic salmon (Stasko 1975), where fish attained net movements by drifting with flood tides and holding against ebb tides, and sockeye salmon which showed a great variety of movement patterns, but tended to follow axes of tidal currents (Stasko et al. 1976).

Much of what is known about guidance mechanisms of fish migration is based on extensive work with Pacific salmon species, although a variety of other fishes have been studied (see reviews by Harden Jones 1968; Hasler 1971; Leggett 1977). Early work documented the accuracy of salmon homing and resulted in the Parental or Home Stream Theory. A number of hypotheses, often based on mechanisms known to operate in other animals, were proposed and tested (e.g., inertial navigation, sensing of magnetic fields, sun-compass orientation and responses to polarized light). However, as Leggett (1977) points out, most of these hypotheses are not adequately supported by observational or experimental evidence or are known in only one or a few species. Recent work has suggested more parsimonious explanations of homing success in fishes. Rather than highly directed movements and precise orientation, a number of investigators argue that fish attain homing through very low level responses to environmental variables (Saila and Shappy 1963; Patten 1964; Harden Jones 1968). Under this hypothesis, fish move in apparently random patterns that are altered by responses to environmental conditions. Such mechanisms are consistent with information on juvenile salmon migration from fresh to salt water (McInerney 1964; Byrne 1971; Brannon 1972), and have also been used to explain seasonal movements in two coregonid species, *Leucichthys artedi* (Fry 1937) and *Coregonus muksun* (Leggett 1977). A number of environmental variables may be involved in the responses of fishes that result in these 'directed' semi-random movements; temperature and salinity are obvious possibilities (Favorite and Hanavan 1963; Konstantinov 1965; Banks 1969). Fujii (1975) has demonstrated that the timing and direction of migration of sockeye salmon in Bristol Bay result from selection of temperature and salinity regimes.

Although fish migrations are likely to be directed by the modified random walk mechanism described above, it is still necessary for a fish to recognize its home or destination when it is encountered. Convincing experimental evidence from salmon species indicates that olfaction is the sensory mechanism used to recognize home streams (Fagerlund et al. 1963; Cooper et al. 1976). This olfactory recognition may be based on chemical characteristics of home stream water (Hasler and Wisby 1951) or on intraspecific recognition (pheromones) (Höglund and Åstrand 1973; Doving et al. 1974).

Possible Development Effects. The migration cues used by Beaufort Sea anadromous species have not been identified; however, each of the two general types of migrations (navigation or modified random walk) have characteristics that would have implications for assessment of possible impacts. If fish responded precisely to extrinsic navigation aids such as the sun, magnetic fields or polarized light, most environmental impacts would have little effect on their navigational cues. However, recent studies and reviews of fish migration suggest that the modified random walk hypothesis is often involved. If fish movements are indeed imprecise responses based on water conditions such as temperature and salinity or on odors, alteration of the nearshore marine environment might have a detrimental impact on their success in returning to overwintering and spawning locations. Altered current patterns could not only affect temperature and salinity patterns, but could prevent waterborne olfactory cues from reaching areas where they may now be used by fish.

A second way that development in nearshore waters might affect the migration of fishes is through direct obstruction of migration corridors. Concern has been raised that causeways which jut several kilometers into coastal waters may impede the longshore movements of fish. One such causeway now exists in Prudhoe Bay. A preliminary report concludes that it is not a barrier to fish movements (Doxey 1977); however, more complete analyses of existing data are required before this conclusion will be convincing.

Spawning and Overwintering

Marine nearshore waters of the Beaufort Sea are important to marine species of fish (arctic cod, fourhorn sculpin, saffron cod and snailfish species) for spawning (primarily in winter) and overwintering. One anadromous species, the boreal smelt, also inhabits nearshore waters during the winter.

For marine fishes with demersal adhesive eggs, such as the snailfish, availability of substrates suitable for egg deposition may limit spawning success. For others with planktonic eggs (e.g., arctic cod), there should be virtually unlimited spawning habitat, since environmental variables such as under-ice conditions, temperature and salinity are probably relatively uniform over extensive areas. However, in shallow areas like Simpson Lagoon, bottom-fast ice, hypersaline conditions and minimal amounts of free water probably exclude these areas as suitable winter habitats for either spawning or overwintering.

Another factor that affects fish use of marine nearshore environments in winter is freezing resistance. Fish are normally iso-osmotic at salinities of 7.5-11 ppt; their freezing points are, therefore, higher than the surrounding water in areas of higher salinity. It has been observed that marine species have adapted physiologically and behaviorally to cope with this problem (DeVries 1974). However, there is no evidence that freshwater or anadromous species have compensated physiologically for freezing temperatures; therefore, their winter migration into brackish and fresh waters may be essential. For example, both arctic and least cisco show a preference for habitats with brackish water during the ice-free period and this trend continues during the winter when they move into the brackish waters of the Colville Delta. Brackish waters of the delta may be less of a physiological stress than higher-salinity nearshore marine water in winter. Strawn and Dunn (1967) have shown that euryhaline fish subjected to cold stress shift salinity preference toward the salinity levels of their habitats of evolutionary origin; fish from fresh water shift their preferences in that direction and marine-originating species shift preferences to higher salinities. Arctic and least cisco have freshwater antecedents; therefore, it would be expected that under cold stress their salinity optima would be lowered.

Although winter information is limited, several general observations can be made about nearshore habitats and their use by fish. First, fishes are not evenly distributed throughout the nearshore zone in winter. Even within the relatively small area sampled, differences in distribution were noted during the present study. Most boreal smelt, fourhorn sculpin and saffron cod were caught in Harrison Bay, while most arctic cod and snailfish were caught in Stefansson Sound (although these catches may reflect differences in the sampling gear used). Second, since there is a continual process of ice deposition through the winter, characteristics of nearshore marine habitats slowly change and distributions of fishes may change accordingly. For example, Simpson Lagoon is used by arctic cod and boreal smelt in November, but it is apparently devoid of fish by February, probably in response to decreasing amounts of free water and/or increasing salinities.

Third, for the anadromous species which leave marine waters and return to rivers to spawn and overwinter, impacts on freshwater systems are likely to be most critical if they occur during the winter period. In summer, various components of the cisco, char and whitefish populations are widely distributed in coastal and fresh waters. However, in winter, they are concentrated in rivers, generally in relatively small, sometimes isolated pockets of water which remain unfrozen during the extended winter period. It is generally thought that these fish are vulnerable to adverse impacts during the winter, perhaps more so than at any other stage of their life cycle. The importance of overwintering areas to northern fish populations and the land-use conflicts that have arisen concerning overwintering fish and industrial development (e.g., winter water withdrawal, gravel removal, pipeline trenching, contaminants) have been described in recent studies and reviews (Craig and McCart 1974; Bendock 1976; Ward and Peterson 1976; Wilson et al. 1977). From this viewpoint, it is likely that onshore effects, rather than offshore effects, pose the greater threat to anadromous fishes.

CONCLUSIONS

1. Nearshore Fish Populations

Although 22 fish species were caught in Simpson Lagoon, five fish species accounted for over 90% of all fish caught during the summers of 1977 and 1978. These include two marine species (arctic cod, fourhorn sculpin) and three anadromous species (arctic cisco, least cisco, arctic char).

Fish numbers and species composition changed markedly between the two summers. Catches in 1978 included all species caught in 1977 plus eight additional species, including pink salmon. Massive numbers of arctic cod, many times more than were encountered in 1977, swept through the lagoon system during a nine-day period in mid-August of 1978.

In winter, the species composition in nearshore waters changes, largely because most anadromous fish leave coastal waters. Several marine species (principally arctic cod and fourhorn sculpin) and one anadromous species (boreal smelt) inhabit deeper nearshore areas under the ice.

2. Habitat Use

The relatively warm and brackish waters lying adjacent to the coastline provide important summer habitat for anadromous fishes and some marine species. Fish rapidly invade previously frozen regions of Simpson Lagoon each summer. Numbers of anadromous fish in colder and more saline offshore waters are negligible; it is postulated that there are physiological advantages, and perhaps requirements, for these fish to remain in the warmer nearshore environment.

Fish were distributed throughout nearshore waters in summer, but anadromous fish were most abundant along the mainland shoreline where waters were relatively warm and brackish. The densest concentrations often occurred within 100 m of the shoreline. Anadromous species were less abundant along barrier island shorelines and in the central part of the lagoon; marine species tended to be more evenly distributed.

In winter, several species use nearshore habitats for spawning and/or overwintering. Fish are eventually excluded from shallow areas (< 2 m deep) as ice thicknesses and salinities increase. Differences in winter distributions of marine fishes in nearshore waters were observed.

3. Movements and Migration

Anadromous fish arrive with the first signs of spring breakup, disperse along the coastline, and return in fall to river drainages to spawn and/or overwinter. Marine species tend to increase in abundance in nearshore waters as the open-water season progresses. For all species, numbers of juvenile and adult fish constantly change because of day-to-day pulses of movement and large-scale population movements over periods of several weeks. Numbers of fish caught daily were usually not correlated significantly with daily changes in water temperature, salinity or turbidity, but experimental data are required to investigate these relationships.

Interpretation of tagging results indicated that the summer residency times for individuals of anadromous species in Simpson Lagoon probably averaged 14-24 days if fishes traveled through the lagoon during movements from and back to their rivers of origin. On the other hand the fourhorn sculpin, a marine species, is relatively sedentary and individuals may reside in the same general area for a year or more.

4. Feeding Ecology

Dietary overlap among fishes was high. A few epibenthic mysids (*Mysis litoralis*, *M. relicta*), amphipods (*Onisimus glacialis*), and other invertebrates accounted for most of the fishes' diets.

The available supply of invertebrate food in the lagoon averaged about 1-2 orders of magnitude greater than the total daily food requirements of all vertebrate consumers (fish and birds) in Simpson Lagoon (Griffiths and Dillinger 1980). It is postulated that this high food level is maintained principally by continued invertebrate immigration, seasonally limited access to prey, and growth of prey. Chronic natural fluctuations in the physical habitat apparently perpetuate an early successional stage characteristic of 'pioneer' communities.

The daily food ration of arctic cod was estimated under field conditions to be 6% of body weight per day. At this rate, it is likely that the large numbers of this species that entered Simpson Lagoon in August 1978 may have contributed to the decline in mysid biomass described by Griffiths and Dillinger (1980).

5. Fishing Pressure, Predation and Parasites

Due to their coastal migrations, anadromous fish passing through Simpson Lagoon are harvested by man at widespread locations. Fish tagged in Simpson Lagoon were recaptured in domestic, commercial and sport fisheries across most of the Alaskan Beaufort Sea coastline. The commercial fishery in the Colville Delta harvests an estimated 9% of the arctic cisco which are susceptible to the fishery and 5% of the least cisco. Domestic fishing by the village of Nuiqsut, also located in the Colville Delta, is thought to harvest a similar amount.

Populations of fishes in the nearshore environment do not appear limited by predation pressure or parasite loads. Mammal, bird and fish predation was negligible in areas where fish were abundant. Parasite loads of arctic cisco were low and did not appear to detrimentally affect their health.

6. Cisco Population Sizes

Based on Peterson mark/recapture procedures, population estimates were made of two anadromous fishes important to man, arctic and least cisco. These estimates include only individuals that were of a size (> 250 mm length) vulnerable to the commercial fishery in the Colville Delta but excluding spawners. Data indicate that populations of arctic cisco from the Colville River have declined roughly 86% from 777,000 fish in 1976 to 110,000 fish in 1979; least cisco have increased roughly 83% from 305,000 fish in 1976 to 1,773,000 fish in 1979. Reasons for these apparent changes are not known.

RECOMMENDED FURTHER RESEARCH

Several topics requiring further research are briefly described below:

1. Critical habitats. Major gaps exist in our understanding of the life-histories of several key fish species that may be affected by industrial developments in the arctic. We cannot at this time identify where some of these species spawn or overwinter.

   The arctic cisco is especially poorly known. The Colville River is probably the major source of arctic cisco along the Alaskan Beaufort Sea coastline, yet we do not know where these fish spawn. No spawners were found by us during a reconnaissance of potential spawning areas. Similarly, little is known about where this species overwinters except that the Colville River is used. Our studies also indicate that the population size of this important species has declined markedly over the past two years. The implications of this reduction, in view of the annual harvest by subsistence and commercial fisheries, must be examined.

   Spawning and overwintering areas are also poorly known for arctic cod and other marine fishes.

2. Habitat requirements. The importance of nearshore waters to anadromous fish populations has been documented. These fish apparently do not stray far from the relatively warm and brackish waters along the coastline. These nearshore temperature and salinity regimes may be affected by industrial developments, such as causeways, which alter nearshore current patterns. It is important, therefore, to determine how fish will be affected by changes in these physical factors. Experimental assessments of the temperature and salinity preferences and tolerances of selected anadromous fishes are needed.

3. Regional data gaps. Fish use of two Beaufort Sea regions is poorly documented. The first of these regions includes all offshore waters, especially those in the 3-20 m depth zone. Virtually all fisheries studies to date have emphasized fishes, particularly the anadromous species, inhabiting shallow nearshore waters--typically less than 3 m deep. Although industrial developments will take place in the 3-20 m zone, little is known about the importance of this region to fish populations. Arctic cod spawn and overwinter in these waters, but specific important areas are not well known.

The second region requiring investigation is the coast between the Colville River and Barrow. This region lies 'downstream' of the proposed lease area due to prevailing nearshore currents of the Beaufort Sea. Preliminary evidence indicates that the species composition of fish in this area may differ from that between the Colville and Mackenzie rivers. Streams draining into the former region support important anadromous whitefish and least cisco populations, whereas in the latter region streams support arctic char populations. This regional difference in fish usage largely reflects hydrological differences between the two areas. It is thought that char are absent from streams between Barrow and the Colville River because these coastal drainages generally lack the perennial springs that are associated with the spawning grounds of char. Given these differences between drainages and fish populations in these two regions, it is difficult to extrapolate coastal data from one region to the other. We therefore recommend that the coastal region between Barrow and the Colville River be examined.

4. Fish versus nearshore obstructions. Concern has been raised that causeways which jut into coastal waters may affect arctic fish populations in several ways. By altering prevailing nearshore currents, causeways may affect temperature and salinity regimes in areas where fish concentrations are highest (addressed above), or disrupt the rate at which the food organism of fishes (mysids, amphipods) disperse into nearshore areas (addressed in Griffiths and Dillinger 1980). Causeways may also affect migrations of anadromous species through physical blockage or possibly through disruption of orientational processes. Although a summary report regarding this concern was prepared by the Alaska Department of Fish and Game (Doxey 1977), the problem requires review and complete data analysis before this issue will be resolved. Further field experimentation may be required.

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APPENDICES

APPENDIX 1

BEST DOCUMENT AVAILABLE

APPENDIX 1. Tag and recapture data (as of November 1979) for fish recovered during this study, Simpson Lagoon 1977-79. Site abbreviations are listed below.

1. LEAST CISCO

	Tag		Recapture	
F.L.	Site	Date	Site	Date
345	MP	15- 8-77	MP	17- 8-78
295	MP	7- 8-78	MP	9- 8-78
295	MP	7- 8-78	MP	9- 8-78
310	MP	17- 7-78	MP	15- 8-78
280	MP	15- 7-78	CD	13-10-78
315	MP	22- 7-78	CD	14-10-78
340	MP	19- 7-78	CD	14-10-78
290	MP	7- 8-78	CD	14-10-78
330	MP	17- 7-78	CD	16-10-78
355	MP	19- 7-78	CD	16-10-78
320	MP	22- 7-78	CD	19-10-78
330	MP	15- 7-78	CD	19-10-78
310	MP	10- 7-78	CD	19-10-78
-	MP	7-78	CD	21-10-78
325	KP	8- 8-78	CD	23-10-78
315	MP	8- 7-78	CD	23-10-78
325	KP	8- 8-78	CD	23-10-78
255	MP	4- 8-78	CD	25-10-78
360	MP	8- 7-78	CD	26-10-78
320	MP	17- 7-78	CD	28-10-78
310	MP	17- 7-78	CD	30-10-78
315	MP	15- 7-78	CD	30-10-78
310	MP	15- 7-78	CD	1-11-78
335	MP	19- 7-78	CD	4-11-78
295	MP	22- 7-78	CD	6-11-78
330	MP	22- 7-78	CD	6-11-78
325	MP	7- 8-78	CD	7-11-78
330	MP	17- 7-78	CD	7-11-78
335	MP	11- 7-78	CD	7-11-78
290	MP	15- 7-78	CD	7-11-78
325	MP	17- 7-78	CD	11-11-78
320	MP	15- 7-78	CD	13-11-78
310	MP	11- 7-78	CD	16-11-78
320	MP	14- 7-78	CD	16-11-78
290	MP	22- 7-78	CD	18-11-78
315	MP	16- 8-77	CD	31-10-77
315	MP	15- 8-77	CD	31-10-77
300	MP	18- 8-77	CD	25-11-77
298	MP	15- 8-77	B	24-10-77
336	*PB	1- 8-76	MP	6- 8-77
319	*PB	1- 8-76	MP	23- 8-77
355	*PB	10- 8-76	MP	23- 8-77
330	*PB	31- 8-76	MP	1- 7-78
310	*PB	23- 7-76	MP	3- 7-78
330	*PB	23- 7-76	MP	8- 7-78
352	*PB	21- 7-76	MP	9- 7-78
345	*PB	31- 7-77	MP	15- 7-78
320	*PB	17- 8-76	MP	15- 7-78
350	*PB	15- 8-76	MP	15- 7-78
340	*PB	23- 7-76	MP	15- 7-78
-	*PB	31- 7-76	MP	17- 7-78
-	*PB	1- 8-76	MP	17- 7-78
343	*PB	13- 8-76	MP	19- 7-78
349	*PB	24- 7-77	MP	20- 7-78
323	*PB	25- 8-76	MP	21- 7-78
350	*PB	16- 8-76	MP	22- 7-78
335	*PB	3- 8-76	MP	1- 8-78
-	*PB	28- 7-77	MP	2- 8-78
320	*PB	19- 7-76	MP	7- 8-78
320	*PB	20- 7-76	KP	8- 8-78
-	*PB	10- 8-76	MP	15- 8-78
325	*PB	23- 7-77	MP	13- 8-78
-	*PB	31- 7-76	KP	15- 7-78
325	*PB	25- 7-77	MP	19- 8-78
-	*PB	7- 8-77	OP	5- 8-78

APPENDIX 1. (cont'd).

BEST DOCUMENT AVAILABLE

F.L.†	Tag Site	Tag Date	Recapture Site	Recapture Date
1. LEAST CISCO (Cont'd)				
310	MP	11- 7-78	CD	10-78
320	MP	14- 7-78	CD	10-78
310	MP	15- 7-78	CD	10-78
320	MP	24- 7-78	CD	10-78
320	MP	27- 7-78	KP	21- 7-79
375	MP	8- 7-78	KP	28- 7-79
315	KP	18- 7-79	KP	22- 7-79
295	KP	18- 7-79	KP	24- 7-79
260	KP	22- 7-79	KP	26- 7-79
285	KP	18- 7-79	UP	23- 7-79
320	*PB	31- 7-76	MP	23- 7-79
320	*PB	12- 8-76	MP	23- 7-79
285	MP	22- 7-78	CD	14-10-79
290	KP	17- 7-79	CD	16-10-79
322	MP	8- 7-78	CD	20-10-79
310	KP	18- 7-79	CD	20-10-79
325	MP	18- 8-77	CD	22-10-79
295	MP	17- 7-78	CD	22-10-79
295	MP	17- 7-78	CD	22-10-79
305	MP	18- 7-79	CD	22-10-79
315	MP	10- 7-78	CD	23-10-79
310	KP	8- 8-78	CD	23-10-79
300	MP	7- 8-78	CD	23-10-79
-	MP	11- 7-78	CD	23-10-79
335	MP	19- 7-78	CD	26-10-79
-	MP	7-78	CD	26-10-79
320	MP	19- 7-79	CD	31-10-79
325	MP	7- 8-78	CD	5-11-79
290	MP	15- 7-78	CD	6-11-79
325	KP	24- 7-79	CD	7-11-79
340	MP	17- 7-78	CD	8-11-79
335	MP	24- 7-78	CD	8-11-79
325	MP	24- 7-78	CD	8-11-79
305	MP	21- 8-77	CD	19-11-79
315	MP	17- 7-78	CD	17-11-79
300	MP	17- 7-78	CD	17-11-79
350	MP	19- 7-78	CD	19-11-79
350	MP	17- 7-78	CD	23-11-79
345	MP	8- 7-78	CD	15-11-79
310	KP	17- 7-79	CD	19-11-79
305	MP	18- 7-79	CD	12-11-79
315	MP	28- 7-79	CD	9-11-79
340	MP	22- 8-77	CD	10-11-79
340	MP	19- 7-78	CD	10-11-79
2. ARCTIC CISCO				
321	MP	16- 8-77	CD	31-10-77
298	MP	15- 8-77	CD	26-10-77
365	MP	15- 8-77	CD	10-11-77
308	MP	15- 8-77	CD	19-11-77
350	MP	10- 7-78	MP	9- 8-78
-	*PB	8- 8-77	MP	4- 7-78
-	MP	8-78	CD	13-10-78
340	MP	15- 7-78	CD	14-10-78
295	MP	14- 8-77	CD	16-10-78
277	MP	17- 8-77	CD	16-10-78
345	MP	22- 7-78	CD	16-10-78
310	MP	13- 7-78	CD	16-10-78
355	MP	17- 7-78	CD	17-10-78
320	MP	15- 7-78	CD	17-10-78
320	MP	20- 7-78	CD	20-10-78
315	MP	17- 7-78	CD	21-10-78
320	MP	19- 7-78	CD	25-10-78
345	MP	20- 7-78	CD	27-10-78
-	MP	8-78	CD	30-10-78
340	MP	17- 7-78	CD	30-10-78
-	MP	8-78	CD	1-11-78

APPENDIX 1. (cont'd).

F.L.†	Tag		Recapture	
	Site	Date	Site	Date
2. ARCTIC CISCO (cont'd)				
330	MP	11- 7-78	CD	1-11-78
-	MP	8-78	CD	4-11-78
-	MP	8-78	CD	4-11-78
310	MP	19- 7-78	CD	8-11-78
-	MP	8-78	CD	10-11-78
-	MP	8-78	CD	13-11-78
325	MP	17- 7-78	CD	14-11-78
315	MP	20- 7-78	CD	16-11-78
340	MP	17- 7-78	CD	18-11-78
-	MP	8-78	CD	21-11-78
330	MP	15- 7-78	CD	21-11-78
310	MP	20- 7-78	CD	5-12-78
360	MP	14- 7-78	CD	15-12-78
320	MP	13- 7-78	CD	10-78
-	KP	18- 8-78	GP	31- 7-79
350	MP	20- 7-78	CD	22-10-79
295	MP	19- 7-79	CD	22-10-79
355	MP	8- 7-78	CD	27-10-79
295	MP	17- 7-78	CD	27-10-79
250	MP	18- 7-79	CD	27-10-79
300	KP	18- 7-79	CD	5-11-79
285	KP	17-7-79	CD	5-11-79
320	KP	18- 7-79	CD	6-11-79
260	KP	18- 7-79	CD	19-11-79
3. ARCTIC CHAR				
252	MP	25- 7-78	MP	19- 8-78
360	MP	4- 9-78	OP	5- 9-78
380	MP	19- 7-78	CR	9-78
615	MP	4- 8-78	IR	9- 8-79
533	*IR	17- 9-72	LI	3- 8-77
649	*IR	9- 9-72	LI	26- 7-77
600	*IR	24- 8-72	MP	18- 8-78
3. ARCTIC CHAR (cont'd)				
680	*IR	14- 7-74	MP	26- 8-78
-	*IR	13- 9-72	KP	16- 8-78
555	*IR	19- 9-71	MP	19- 7-78
-	*PB	29- 7-77	P	8- 7-78
600	*PB	31- 7-76	MP	6- 8-78
620	*PB	8- 8-76	MP	18- 8-78
560	*SR	21- 8-71	MP	26- 8-78
4. BROAD WHITEFISH				
434	*PB	9- 8-76	MP	30- 6-78
380	MP	1- 7-78	MP	7- 8-78
403	MP	3- 9-78	OP	5- 9-78
340	MP	10- 7-78	CD	10-78
5. HUMPBACK WHITEFISH				
400	*PB	16- 7-76	MP	25- 7-77
408	*PB	19- 7-76	MP	5- 8-77
402	*PB	2- 9-76	MP	1- 7-78
425	MP	10- 7-78	KP	19- 7-79
6. FOURHORN SCULPIN				
144	PI	24- 8-77	PI	29- 8-77
207	PI	27- 8-77	PI	27- 8-77
129	MP	21- 8-77	MP	23- 8-77
134	PI	15- 8-77	PI	1- 9-77
212	MP	17- 8-77	PI	4- 9-77
160	MP	17- 8-77	PI	6- 9-77
168	MP	27- 8-77	MP	16- 9-77
114	MP	23- 8-77	MP	28- 8-77
160	MP	23- 8-77	MP	28- 8-77
162	PI	1- 9-77	PI	3- 9-77

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APPENDIX 1. (cont'd).

F.L.[+]	Tag Site	Tag Date	Recapture Site	Recapture Date
6. FOURHORN SCULPIN (cont'd)				
207	MP	26- 8-77	MP	28- 8-77
197	MP	26- 8-77	MP	29- 8-77
190	MP	27- 8-77	MP	29- 8-77
135	MP	28- 8-77	MP	22- 7-78
240	PI	16- 8-77	MP	20- 8-78
214	MP	26- 8-77	MP	31- 8-78
195	MP	26- 8-77	MP	5- 9-78
7. ARCTIC FLOUNDER				
195	MP	30- 7-77	MP	21- 8-77
8. ARCTIC COD				
165	MP	19- 9-77	MP	21- 9-77
9. PINK SALMON				
430	MP	6- 8-78	BI	9-78

[+] F.L. Fork length (mm).

*Tagged by the Alaska Dept. Fish and Game.

Sites

B - near Barrow
BI - Barter Island
CD - Colville Delta
CR - Canning River
GP - Griffin Point
IR - Ivishak River
KP - Kavearak Point (Simpson Lagoon)
LI - Leavitt Island (Simpson Lagoon)
MP - Milne Point (Simpson Lagoon)
OP - Oliktok Point (Simpson Lagoon)
P - Peat Island (Simpson Lagoon)
PB - Prudhoe Bay
PI - Pingok Island (Simpson Lagoon)
SR - Sagavanirktok River
UP - Unnamed point between Kavearak and Beechey Points (Simpson Lagoon)

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APPENDIX 2

APPENDIX 2

A Fish Survey in the Lower Colville River Drainage with an Analysis of Spawning Use by Arctic and Least Cisco

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and
Peter C. Craig

LGL Limited
2453 Beacon Avenue
Sidney, British Columbia, Canada

TABLE OF CONTENTS

Page

ABSTRACT ....

ACKNOWLEDGEMENTS ....

INTRODUCTION...

STUDY AREA ....

METHODS AND MATERIALS ....

RESULTS ....

DISCUSSION ....

  Coastal Lakes ....

  Colville River Mainstream ....

  Tributaries ....

CONCLUSIONS ....

LITERATURE CITED ....

ABSTRACT

A survey was conducted for arctic and least cisco (*Coregonus autumnalis* and *C. sardinella*) spawning grounds in the lower Colville River and nearby drainages during fall 1978 and 1979. A total of 28 locations were sampled and several spawning habitats were identified for least cisco, including deep coastal lakes, the Colville Delta and river upstream as far as Ocean Point. However, only 8 arctic cisco were collected and none was in a spawning condition. Possible locations of arctic cisco spawning grounds are deduced from a review of available survey data for the Colville drainage.

ACKNOWLEDGEMENTS

The authors wish to thank L.J. Haldorson for his efforts in field work. James W. Helmericks, our pilot and guide, provided valuable advice during the planning and sampling stages of the project.

INTRODUCTION

Least cisco (*Coregonus sardinella*) and arctic cisco (*C. autumnalis*) are among the most abundant species in the nearshore waters of the Beaufort Sea and are the main target for local subsistence and commercial fishery operations. Both species are anadromous; they range widely across the Beaufort Sea coast in summer and return to spawn and/or overwinter in North Slope drainages. Based on tagging studies and the location of fall fishing operations, the Colville River is believed to provide winter habitat for many of the ciscoes found in summer within the petroleum lease area near Prudhoe Bay (reviewed by Craig and Haldorson 1980).

There is a considerable amount of information describing these species after they enter coastal waters (see Craig and Haldorson 1980), but in view of their importance to humans, it is surprising that little is known of their fresh water habits. For example, specific areas of spawning and overwintering are poorly known for both species. A need to identify and characterize these areas is essential for future fisheries management policy. Knowledge of this is also important for industrial concerns, since it is generally assumed that freshwater and anadromous fish are most vulnerable to disturbance during the winter period (Craig and McCart 1974; Bendock 1976; Ward and Petersen 1976; Wilson et al. 1977).

The objectives of this study were to survey areas in the Colville River drainage to assess their importance for spawning and overwintering ciscoes. Since previous survey work concentrated within portions of the delta (Kogl 1972; Kogl and Schell 1974) and upper reaches of the river (Kogl 1972; Bendock 1979), locations selected for this study were intended to fill some of the remaining regional gaps. These areas included the Colville River mainstem between the delta and Umiat, tributaries such as the Itkillik, neighboring drainages of the Colville, and an array of deep coastal lakes.

STUDY AREA

The Colville River, the largest Alaskan North Slope river, flows 67 km from its headwaters in the Brooks Range to Harrison Bay in the Beaufort Sea. The drainage encompasses an area of 62,160 km^2 and includes several major tributaries. The Colville is unique among Alaskan North Slope rivers in that it supports the largest and most diverse (22 species) population of freshwater and anadromous fishes (Table 1). Six species of whitefish are found, five of which are anadromous. Two of these, arctic and Bering cisco, are usually allopatric in their distribution (McPhail 1966). Four species of salmon are known to occur; however, their population sizes are small. Resident and anadromous forms of arctic char are found, but in lesser numbers than in the smaller rivers to the east, possibly due to the occurrence of fewer spring-fed tributaries which are important spawning and rearing areas for char (Craig and McCart 1974).

METHODS AND MATERIALS

The survey of cisco spawning and overwintering areas was conducted primarily in the lower Colville River drainage, although several nearby drainages were also investigated. Sampling was conducted during 20-21 August 1978, 8-9 September 1978 and 4-15 September 1979. Lake sampling was limited to lakes deeper than 2 m since shallow lakes freeze solid by late winter. Identification of deep lakes in the lower Colville drainage was simplified through the use of LANDSAT photo-imagery for band 7, which readily distinguishes ice from water. Deep lakes generally retain their ice cover longer than shallow lakes; thus, the presence of ice cover in early summer (July) is indicative of lakes which do not freeze to the bottom during winter. Water depths were checked with a sounding line when sites were visited.

Access to sampling locations was limited to lakes and stretches of river large enough to accommodate a float plane; the smallest accessible area was about 1.5 km in length. These constraints did not limit sampling in lakes, since deep waterbodies are typically large in size. However, small channels in narrow meandering streams and isolated pools in braided streams were not accessible.

Table 1. List of fish species collected in the Colville River drainage. Data sources: Kogl 1972; Kogl and Schell 1974; Bendock 1979; Hablett 1980; Craig and Haldorson 1980; the present study.

Common Name	Scientific Name	Abbreviation
Salmonidae		
Arctic cisco	*Coregonus autumnalis*	ARCS
Broad whitefish	*C. nasus*	BDWF
Humpback whitefish	*C. pidschian*	HBWF
Least cisco	*C. sardinella*	LSCS
Pink salmon	*Oncorhynchus gorbuscha*	PKSN
Chum slamon	*O. keta*	CHUM
Red salmon	*O. nerka*	RDSN
King salmon*	*O. tshawytscha*	
Round whitefish	*Prosopium cylindraceum*	RDWF
Arctic char	*Salvelinus alpinus*	CHAR
Lake trout*	*S. namaycush*	
Arctic grayling	*Thymallus arcticus*	GRAY
Osmeridae		
Boreal smelt	*Osmerus eperlanus (=mordax)*	BORS
Gadidae		
Saffron cod	*Eleginus gracilis*	SFCD
Burbot	*Lota lota*	BURB
Gasterosteidae		
Ninespine stickleback*	*Pungitius pungitius*	
Cottidae		
Slimy sculpin*	*Cottus cognatus*	
Fourhorn sculpin	*Myoxocephalus quadricornis*	FHSC
Umbridae		
Alaska blackfish	*Dallia pectoralis*	BKFH
Esocidae		
Northern pike*	*Esox lucius*	
Catostomidae		
Longnose sucker	*Catostomus catostomus*	LNSR
Pleuronectidae		
Arctic flounder	*Liopsetta glacialis*	ARFL

*Indicates those not found in this study but reported by Bendock (1979).

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Fish were sampled by gill nets (2 x 50 m) comprised of four panels of mesh sizes 2.5, 3.8, 5.1 and 6.4 cm (stretched). Nets were usually set from a point of land; one end was tied to shore and the other anchored to the bottom. Weather permitting, nets were left overnight and retrieved the following day. Laboratory analyses included measurements of fork length (± 1.0 mm), weight (± 1.0 g), gonad weight (±0.1 g) and visual assessment of reproductive condition. Fish were classified as immature (have never spawned), mature green or mature spawner (would spawn in the year of capture), or mature non-spawner (have spawned previously but would not spawn in the year of capture).

RESULTS

The 28 sampling locations were located in the Colville drainage, Fish Creek, Ikpikpuk River, and unnamed drainages (Table 2 and Fig. 1). Many of the lakes sampled were unnamed; for ease in reference, some of these locations have been given unofficial names which are differentiated by quotes.

Most of the fish species in the Colville were represented in our collections (Table 1). Two species, red salmon and saffron cod, have not previously been recorded within the drainage. However, five species (king salmon, lake trout, ninespine stickleback, slimy sculpin and northern pike) reported to occur by Bendock (1979) were not found in this survey.

Least cisco and broad whitefish were the most abundant species collected and were found throughout the study area (Table 3). For all locations combined, these two species comprised 60 and 14% of the total catch, respectively. The remaining species were much less abundant and found at fewer sites. Only 8 arctic cisco were taken, all from waterbodies in the lower delta adjacent to Harrison Bay. During 1978 surveys, three species of salmon (pink, chum and red) were found in different spawning phases; no salmon were found in the 1979 surveys.

The catch per unit effort (CPUE) at sampling sites ranged from 0 to 10 fish per gill net hour (Table 3); however, these values should be used with some caution, since net efficiency at different locations varied. For example, nets set in lakes generally fished more efficiently than those in streams, since moving water carries debris which eventually

Table 2. **Description and location of gillnet sample locations. Abbreviations used to describe fish access to waterbody: 0 (outlet open), X (outlet appears unsuitable for fish passage due to shallow, intermittent, or no flow).**

Site No	Waterbody	Date Sampled	Location	Drainage	Fish Access
1.	Unnamed Lake	05 Sep 79	70°25'N 150°11'W	Harrison Bay	x
2.	Unnamed Lake	05 Sep 79	70°22'N 150°30'W	Colville Delta	X
3.	"Gas" Lake	05 Sep 79	70°18'N 150°30'W	Colville Delta	X
4.	"Blackfish" Lake	05 Sep 79	70°12'N 150°40'W	Colville Delta	0
5.	Unnamed Lake	06 Sep 79	70°09'N 150°43'W	Colville Delta	0
6.	"Loon" Lake	06 Sep 79	70°11'N 150°43'W	Colville Delta	0,X
7.	"Sucker" Lake	06 Sep 79	70°08'N 151°03'W	Colville Delta	0,X
8.	Unnamed Lake	07 Sep 79	69°53'N 151°20'W	Colville Delta	X
9.	Colville River	07 Sep 79	69°58'N 151°36'W	Harrison Bay	0
10.	Colville River	07 Sep 79	70°01'N 151°34'W	Harrison Bay	0
11.	Unnamed Lake	07 Sep 79	70°17'N 150°52'W	None apparent	X
12.	Colville River	08 Sep 79	70°03'N 151°34'W	Harrison Bay	0
13.	"Least" Lake	08 Sep 79	70°23'N 150°51'W	Harrison Bay	0
14.	"Halfway" Lake	08 Sep 79	70°24'N 150°47'W	Harrison Bay	0
15.	"Sculpin" Lake	08 Sep 78	70°26'N 150°45'W	Harrison Bay	0
16.	"Leach" Lake	09 Sep 79	70°18'N 151°33'W	Fish Creek	X
17.	Unnamed Lake	09 Sep 79	70°18'N 151°37'W	Fish Creek	X
18.	"Salt" Lake	09 Sep 79	70°24'N 151°30'W	Harrison Bay	0
19.	Unnamed Lake	09 Sep 79	70°24'N 150°45'W	Harrison Bay	0
20.	"Flounder" Lake	09 Sep 79	70°25'N 151°41'W	Colville Delta	0
21a.	Teshekpuk Lake (west)	10 Sep 79	70°39'N 153°54'W	Ikpikpuk River	0
21b.	Teshekpuk Lake (north)	10 Sep 79	70°38'N 153°11'W	Ikpikpuk River	0
22.	Fish Creek	10 Sep 79	70°21'N 151°18'W	Harrison Bay	0
23.	Colville River	21 Aug 78	70°51'N 151°21'W	Harrison Bay	0
24.	Colville River	21 Aug 78	69°51'N 151°04'W	Harrison Bay	0
25.	Colville River	21 Aug 78	69°31'N 151°26'W	Harrison Bay	0
26.	Itkillik River	09 Sep 78	69°09'N 150°53'W	Colville River	0
27.	Itkillik River	09 Sep 78	69°53'N 150°48'W	Colville River	0
28.	Itkillik River	09 Sep 78	69°34'N 150°53'N	Colville River	0

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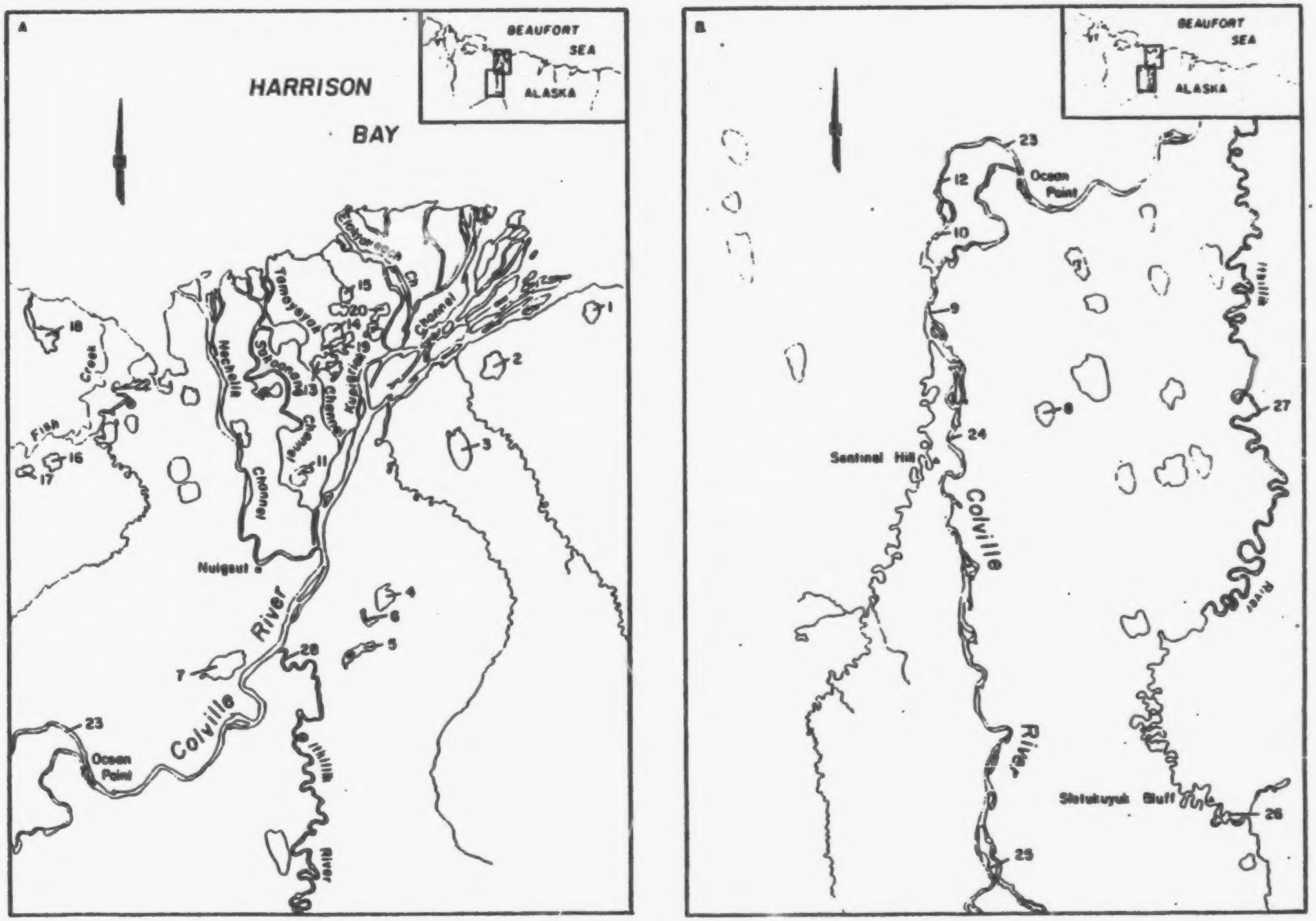
A
HARRISON
BAY
BEAUFORT
SEA
ALASKA
Fish
Creek
Nechelik
Channel
Tamayayak
Sakoonang
Channel
Kupigruak
Channel
Nuigsut
Colville
River
Ocean
Point
Itkillik
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B
BEAUFORT
SEA
ALASKA
Ocean
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Sentinel Hill
Colville
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Itkillik
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Figure 1. Study area, Colville Delta (A) and lower reaches of Colville River (B). Sa[illegible] locations are indicated by collection numbers.

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Table 3. Summary of fish species caught at sampling locations. Abbreviations for fish species are listed in Table 1.

Site No	Waterbody	FISH SPECIES LSCS	BDWF	FHSC	RDWF	GRAY	HBWF	CHAR	BDRS	ARCS	BKFH	BURB	LNSR	PKSN	CHUM	RDSN	SFCD	ARFL	Unid.	Total	Fish/h
1	Unnamed Lake																			0	0.0
2	Unnamed Lake					2														2	0.1
3	"Gas" Lake		1			1														2	0.02
4	"Blackfish" Lake	40	15		2	21					2									80	1.2
5	Unnamed Lake																			0	0.0
5	"Loon" Lake																			0	0.0
7	"Sucker" Lake	132	27		15							1	1							176	2.7
8	Unnamed Lake										4									4	0.2
9	Colville River				4	2		3												9	0.2
10	Colville River	4				1		1												6	0.1
11	Unnamed Lake	217	4		3		1													225	10.0
12	Colville River	1																		1	0.04
13	"Least" Lake	83																		83	4.0
14	"Halfway" Lake	59	41	1					8	1							1			111	1.7
15	"Sculpin" Lake	19	15	82				1	4	2										123	5.3
16	"Leach" Lake	25	8			2														35	1.4
17	Unnamed Lake																			0	0.0
18	"Salt" Lake	21	6	3	2															32	1.3
19	Unnamed Lake		1																2	3	0.2
20	"Flounder" Lake	50	26	4			2		1	5								1		89	4.6
21	Teshekpuk Lake	38	2																	40	*
22	Fish Creek	9	2		2														3	16	*
23	Colville River	7	11		2	4	8	2						2						36	1.4
24	Colville River		1			1		1												3	0.1
25	Colville River		11		56	13	24	2								1				107	5.4
26	Itkillik River							1					1		1					3	0.1
27	Itkillik River																			0	0.0
28	Itkillik River				2			3				1								6	0.3
	Species Total	705	171	90	88	47	35	14	13	8	6	2	2	2	1	1	1	1	5	1192	

*Nets became tangled and debris-filled.

666

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fills the net Teshekpuk Lake and Fish Creek CPUE's are not listed, since nets were in place for 5 days due to inclement weather and they became tangled and filled with debris.

A summary of lengths and maturity of fish sampled is shown in Table 4. In most cases, only adult-sized fish were examined for state of gonadal development; small fish were assumed to be immature. This assumption is reasonable for anadromous fish but not necessarily for fish resident in fresh water. Dwarf populations of least cisco and arctic char are known to occur in Beaufort Sea drainages (e.g., Mann 1974; Craig 1977). None of the arctic cisco captured was judged to be mature-green, although there were several mature non-spawners. Mature green least cisco were common throughout the sampling locations.

DISCUSSION

The results of this study contribute to our understanding of least cisco spawning areas but offer little positive information for arctic cisco. During previous surveys and the present study, no mature-green arctic cisco have been found in the Colville River at a time when these fish are suspected to be on their spawning grounds. In view of these findings, the question arises as to whether arctic cisco select an alternate drainage for spawning. While this possibility is not entirely unreasonable, use of different drainages by the spawning and non-spawning segments of arctic cisco populations has not been reported elsewhere (e.g., Berg 1957; Scott and Crossman 1973). Furthermore, this species is associated with large arctic rivers; the Colville is the largest river on the Alaskan North Slope and it contains enough arctic cisco to support both commercial and domestic fisheries in its delta. It does not seem likely that the arctic cisco in question would use the Colville drainage on some occasions during their life cycle (overwintering) but base their reproductive potential on smaller nearby rivers. Therefore, in the following sections, we review all available data in order to determine the overall distribution and potential spawning sites of arctic and least cisco in the Colville drainage (Figs. 2 and 3).

Table 4. Length and maturity of fish collected. Numbers in parentheses indicate sample size for length measurements. Subsamples of fish, usually adult size, were examined for reproductive condition.

Site No.	Waterbody	Species*	Number Caught	Length (mm)		MATURITY			
				Range	$\bar{x}$	Subsample Size	% Spawners		% Immature or Mature Non-spawners
							Males	Females	
1.	Unnamed Lake	None	0						
2.	Unnamed Lake	GRAY	2	<150		0			
3.	"Gas" Lake	GRAY	1	150		0			
		BDWF	1	137		1	0	0	100
4.	"Blackfish" Lake	GRAY	21			0			
		LSCS	40	88 - 395	204	40	13	3	85
		BDWF	15	107 - 600	440	15	0	0	100
		RDWF	2	186 - 295	240	2	0	0	100
		BKFH	2			0			
5.	Unnamed Lake	None	0						
6.	"Loon" Lake	None	0						
7.	"Sucker" Lake	BDWF	27	109 - 495	273	27	0	0	100
		LSCS	132	105 - 298	196	23	17	17	65
		RDWF	15	305 - 429	374	6	50	17	33
		LNSR	1	380		0			
		BURB	1	810		0			
8.	Unnamed Lake	None	0						
9.	Colville River	CHAR	3	250 - 270	263	0			
		GRAY	2	105 - 250	178	0			
		RDWF	4	250 - 350	296	0			
10.	Colville River	CHAR	1			0			
		GRAY	1			0			
		LSCS	4	225 - 284	262	4	25	50	25
11.	Unnamed Lake	BDWF	5	130 - 555	383	5	0	0	100
		HBWF	1	460		1	0	0	100
		RDWF	3	225 - 405	293	3	0	33	67
		LSCS	217	105 - 330	184	217	0	0	100
12.	Colville River	LSCS	1			0			
13.	"Least" Lake	LSCS	83	130 - 367	221	83	2	1	96
14.	"Halfway" Lake	ARCS	1	195		1	0	0	100
		BDWF	41	85 - 300	136	41	0	0	100
		LSCS	59	87 - 372	191	59	0	3	97
		BORS	8	103 - 280	202	1	0	100	0
		FHSC	1			0			
		SFCD	1			0			
15.	"Sculpin" Lake	CHAR	1	287		0			
		ARCS	2	269 - 307	288	2	0	0	100
		BDWF	15	202 - 442	366	15	0	0	100
		LSCS	19	207 - 404	314	19	0	5	95
		BORS	4	223 - 315	263	4	25	50	25
		FHSC	82			0			

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Table 4 (cont'd)

Site No.	Waterbody	Species*	Number Caught	Length (mm) Range	Length (mm) $\bar{x}$	Subsample Size	MATURITY % Spawners Males	MATURITY % Spawners Females	MATURITY % Immature or Mature Non-Spawners
16.	"Leach" Lake	GRAY	2	132 - 182	157	2	0	0	100
		LSCS	25	102 - 198	150	25	0	0	100
		BDWF	8	96 - 206	140	8	0	0	100
17.	Unnamed Lake	None							
18.	"Salt" Lake	BDWF	6	91 - 97	92	6	0	0	100
		LSCS	21	126 - 304	223	21	0	5	95
		RDWF	2	200 - 206	203	0			
		FHSC	3			0			
19.	Unnamed Lake	BDWF	1	157		1	0	0	100
20	"Flounder" Lake	ARCS	5	247 - 352	309	5	0	0	100
		BDWF	26	120 - 445	309	26	0	0	100
		HBWF	2	332 - 372	352	2	0	0	100
		LSCS	50	130 - 332	259	50	10	4	86
		BORS	1	244		1	100	0	0
		FHSC	4			0			
		ARFL	1	169		0			
21.	Teshekpuk Lake	BDWF	2	122 - 123	122	2	0	0	100
		LSCS	38	110 - 237	136	38	0	0	100
22.	Fish Creek	BDWF	3(2)	230 - 250	240	3	0	0	100
		RDWF	2(1)	250		2	0	0	100
		LSCS	9(8)	155 - 285	253	9	0	11	89
23.	Colville River	CHAR	2	350 - 463	406	2	0	0	100
		GRAY	2	225 - 255	240	0			
		BDWF	11	280 - 520	411	11	18	18	64
		HBWF	8	280 - 405	340	8	12	0	88
		LSCS	7	250 - 315	277	7	43	43	14
		RDWF	2	265 - 280	272	0			
		PKSN	2	480 - 540	510	2	100	0	0
24.	Colville River	CHAR	1	484		1	0	0	100
		GRAY	1	260		0			
		BDWF	1	502		1	0	0	100
25.	Colville River	CHAR	2	336 - 376	356	2	0	50	50
		GRAY	13(1)	140		0			
		BDWF	11(3)	378 - 500	423	3	100	0	0
		HBWF	24(7)	382 - 420	400	7	57	29	14
		RDWF	56(5)	179 - 245	226	0			
		RDSN	1	428		1	100	0	0
26.	Itkillik River	CHAR	1	230		0			
		LNSR	1	405		0			
		CHUM	1	600		1	0	100	0
27.	Itkillik River	None	0						
28.	Itkillik River	CHAR	3	280 - 390	322	3	0	0	100
		RDWF	2	255 - 270	262	0			
		BURB	1	515		0			

*See Table 1.

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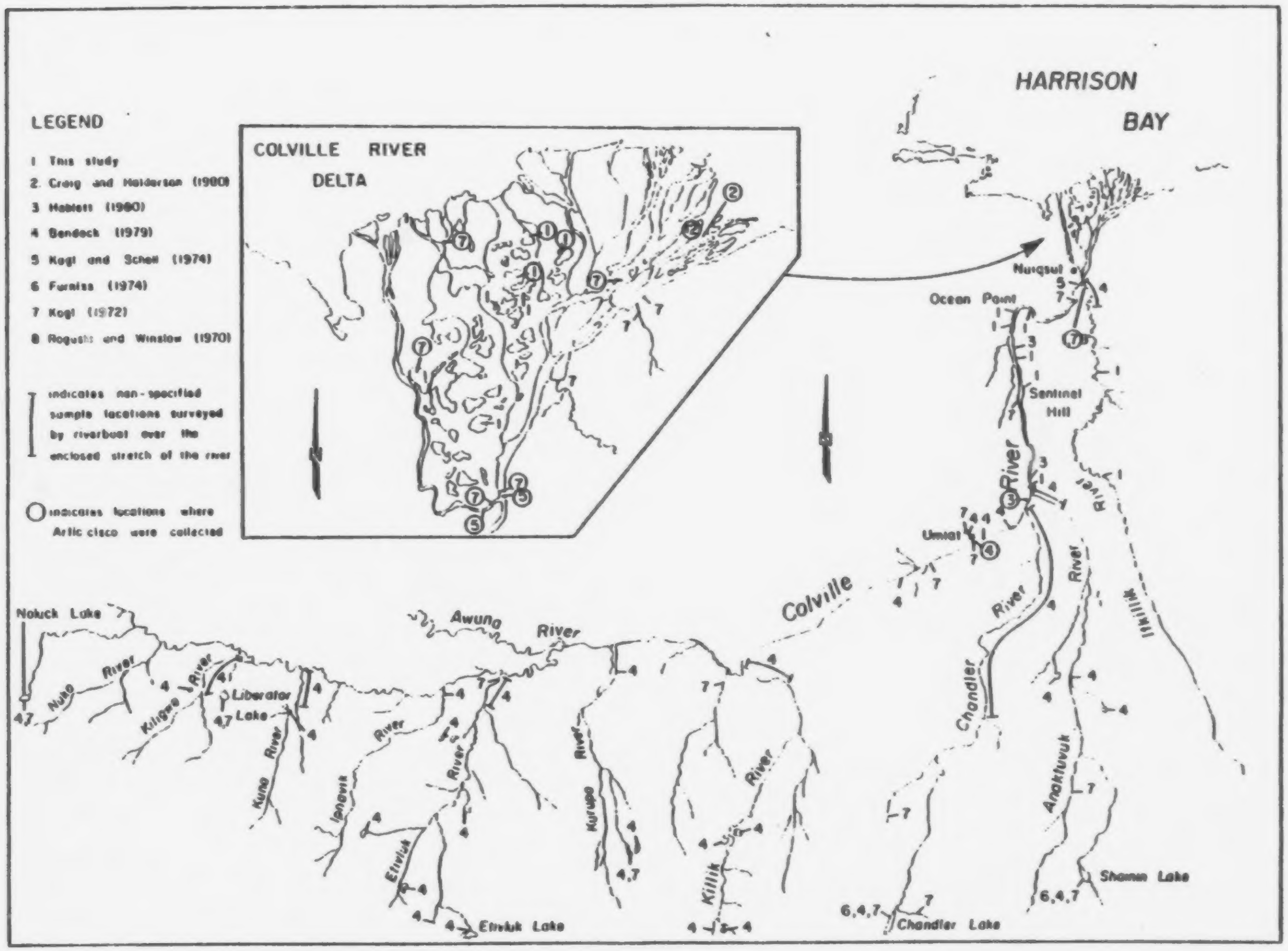
LEGEND
1 This study
2 Craig and Haldorson (1980)
3 Hablett (1980)
4 Bendock (1979)
5 Kogl and Schell (1974)
6 Furniss (1974)
7 Kogl (1972)
8 Roguski and Winslow (1970)
indicates non-specified sample locations surveyed by riverboat over the enclosed stretch of the river
indicates locations where Artic cisco were collected
COLVILLE RIVER DELTA
HARRISON BAY
Nuiqsut
Ocean Point
Sentinel Hill
Umiat
Colville
River
Chandler River
Anaktuvuk River
Itkillik River
Nolück Lake
Nuka River
Kiligwa River
Liberator Lake
Kuna River
Ipnavik River
Awuna River
Etivluk River
Etivluk Lake
Kurupa River
Killik River
Chandler Lake
Shainin Lake

Figure 2. The Colville River drainage showing the locations of fish survey collections. Those locations where arctic cisco have been collected are circled.

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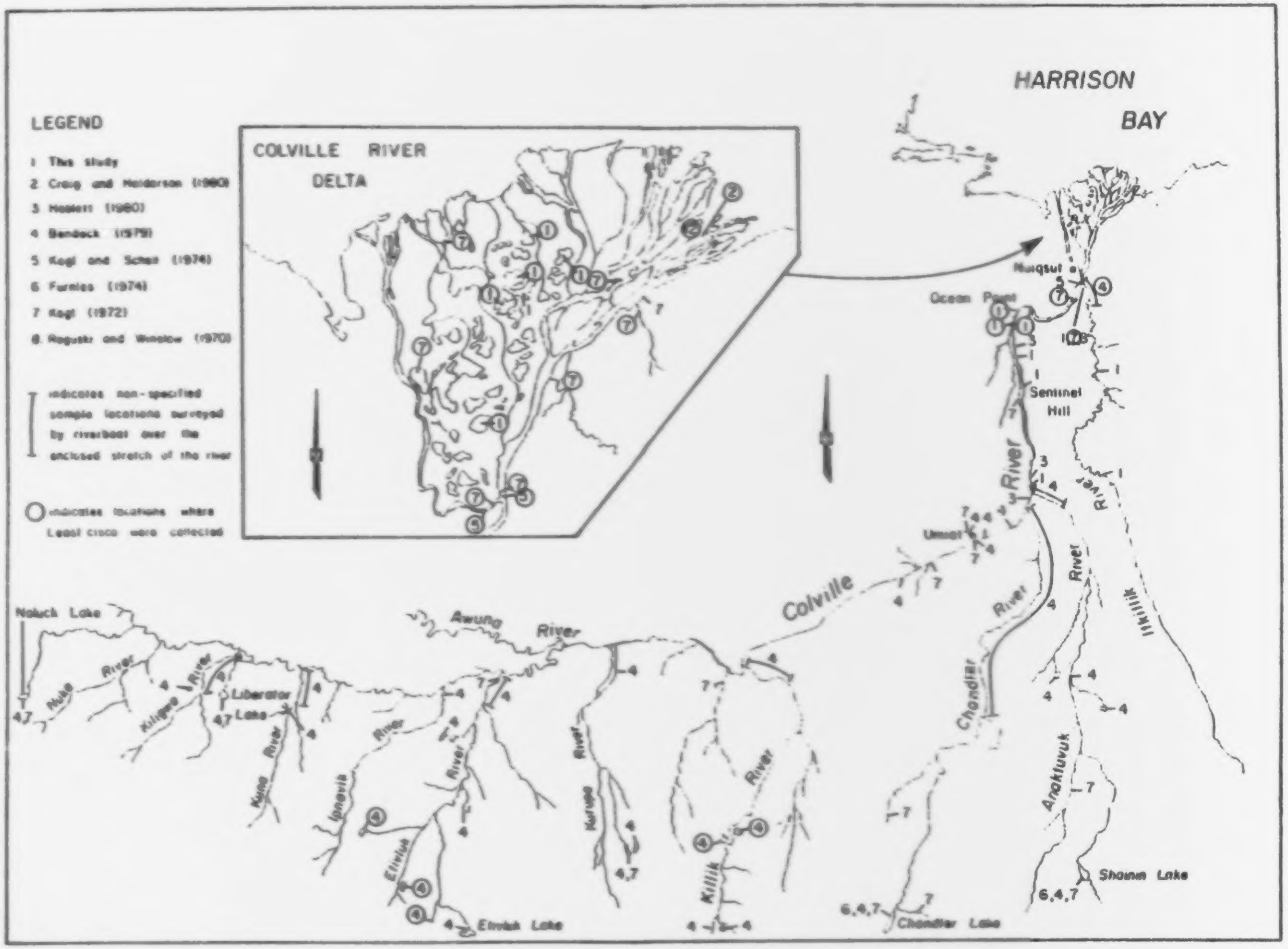
LEGEND
1 This study
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8 Roguski and Winslow (1970)
indicates non-specified sample locations surveyed by riverboat over the enclosed stretch of the river
○ indicates locations where Least cisco were collected
COLVILLE RIVER DELTA
HARRISON BAY
Nuiqsut
Ocean Point
Sentinel Hill
Umiat
Colville
River
Itkillik River
Chandler River
Anaktuvuk River
Shainin Lake
Chandler Lake
Killik River
Kurupa River
Etivluk Lake
Etivluk
Ipnavik River
Kuna River
Liberator Lake
Killigwa River
Nuka River
Awuna River
Nuluck Lake

Figure 3. The Colville River drainage showing the locations of fish survey collections. Those locations where least cisco have been collected are circled.

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Coastal Lakes

It is possible that anadromous ciscoes use lakes for spawning and overwintering since this has been observed for least cisco in other Beaufort Sea drainages (Wohlschlag 1954; Mann 1974). Arctic cisco apparently spawn in rivers (Scott and Crossman 1973) but they too are known to occur in lakes near our study area (e.g., Teshekpuk Lake) (Bendock 1979). However, none of the lakes sampled contained arctic cisco in a spawning condition (mature-green). The only arctic cisco collected (n = 8) were in brackish lakes adjacent to and connected with Harrison Bay, and it is likely that these non-spawning fish were part of the same anadromous population found in nearby coastal habitats. The possibility that arctic cisco had not yet entered the lakes is ruled out, since the water levels in most outlets were low, making them impassable to fish. Consequently, it does not appear that lakes are used for spawning by arctic cisco.

In contrast, least cisco abound in coastal lakes. They represent the most abundant species captured. Virtually all least cisco populations had some mature-green fish, although their percentages were low (average 8.1% mature-green fish). Because of the scope of the study, no attempt was made to distinguish anadromous and non-migrating populations of least cisco. Some, or perhaps most, of the fish were probably nonmigratory. This was particularly apparent in 'Blackfish' Lake (Site No. 4) where least cisco were stout and contained visceral fat, a condition unusual in anadromous populations (Wohlschlag 1954).

Colville River Mainstream

The middle and lower reaches of the Colville River have long been regarded as the spawning locations for ciscoes since almost no ciscoes have been caught as far upstream as Umiat. Evidence supporting this stems from fish inventory work by the Alaska Department of Fish and Game. A gill net station was operated in the Umiat area from early June (following breakup) to early September, but no arctic or least cisco were reported during the 1730 hours of gill net operation (Kogl 1972). Bendock (1970) conducted gill net and angling sampling from several locations in the Colville River primarily upstream from Umiat during the summers of 1977 and 1978 and under-ice gillnetting during fall 1977 and late winter 1978. Again, no arctic cisco were taken from any locations above Umiat, although three male arctic cisco, judged to be mature-green, were taken in mid-June 1977 at Seabee Creek near Umiat. Hablett (1980) also lists arctic cisco captured from the mainstem between the mouths of Anaktuvuk and Chandler Rivers. In view of the low number caught in the middle reaches of the Colville, it is unlikely that their distribution extends upriver beyond Umiat.

However, there is also little substantive evidence that arctic cisco spawn in the Colville River downstream from Umiat. While this species has been recorded throughout the delta region and upstream as far as the mouth of Itkillik River (Fig. 2), none was judged to be in spawning condition (Kogl 1972). Roguski and Winslow (1970) noted that three of the eight arctic cisco in their sample were potential spawners but they do not separate Colville Delta fish from those taken at Thetis Island in Harrison Bay. Farther upstream, between the Itkillik River and Umiat, no arctic cisco have been taken (this study); however, more collections should be made in this area, since sampling has been limited.

In contrast, mature-green least cisco were collected throughout the lower Colville. Kogl (1972) reports that 75% of 100 least cisco taken in Colville Delta in July were judged to be potential spawners. Some ripe and spawned-out least cisco are also evident in the fall commercial fishery at the lower delta (J.W. Helmericks, pers. comm.). Above the delta, anadromous least cisco occur as far as Ocean Point (Site No. 23) but have not been recorded farther upstream. Much like the delta sample, 86% of the 7 least cisco taken at Ocean Point were mature-green (Table 4). Least cisco were also collected in several headwater lakes (Fig. 3), but these are probably non-migratory populations.

Tributaries

Downstream from Umiat, three major tributaries (Itkillik, Anaktuvuk and Chandler rivers) are apparently suitable habitats for fall spawning fish, and perhaps for ciscoes.

During our survey of the Itkillik, spawned-out pink and chum salmon were observed on the gravel banks at the upper station at Siotukoyuk Bluff (Site No. 26) and at the river mouth (Site No. 28). Bendock (1979) reported pre-spawning broad and humpback whitefish entering this river in late August.

A similar situation was also noted in the Anaktuvuk River; during an aerial survey in early October 1978, a large concentration of fish was observed in the middle reaches of the river adjacent to Roof Top Ridge (Bendock 1979). Unfortunately, the absence of suitable landing space for aircraft prevented identification of these fish. The Anaktuvuk and Chandler Rivers are further distinguished as potential spawning habitats by the availability of unfrozen water in spring-fed tributaries in the middle and upper reaches. Bendock (1979) notes that fields of aufeis occur along these rivers through the summer, and a number of other icings have been tentatively identified (Wilson et al. 1977). Kogl and Schell (1974) observed an open-water stretch of river several hundred meters in length in the Chandler River during early May 1972 about 80 km above its mouth. No evidence of spawning was obtained, although grayling were observed and algae and insects were abundant.

While use of these tributaries for spawning by arctic cisco remains undocumented, the possibility deserves further consideration. From examination of collection records, it is conceivable that an upstream spawning migration could have taken place but was missed by various field crews. Of those collections made below Umiat where collection dates are given, most are clustered in two periods, June-early July and late August through September (Fig. 4). Since the mid-summer gap in survey efforts coincides with the disappearance of mature-green arctic cisco from the coastal regions (Craig and Haldorson 1980), the possibility of an upstream migration during this 5 or 6 week period exists. This is not unreasonable when compared to the timing of the upstream migration of arctic cisco in Siberian Rivers. In the Yenesie and Kolyma rivers, fish cover a distance of 600-1000 km in about a month (Berg 1957). At this rate, the fish could ascend the Colville Delta to the Chandler River, a distance of 170 km, in about one or two weeks. A discussion of movement rates (Craig and Haldorson 1980, see 'Net Rate of

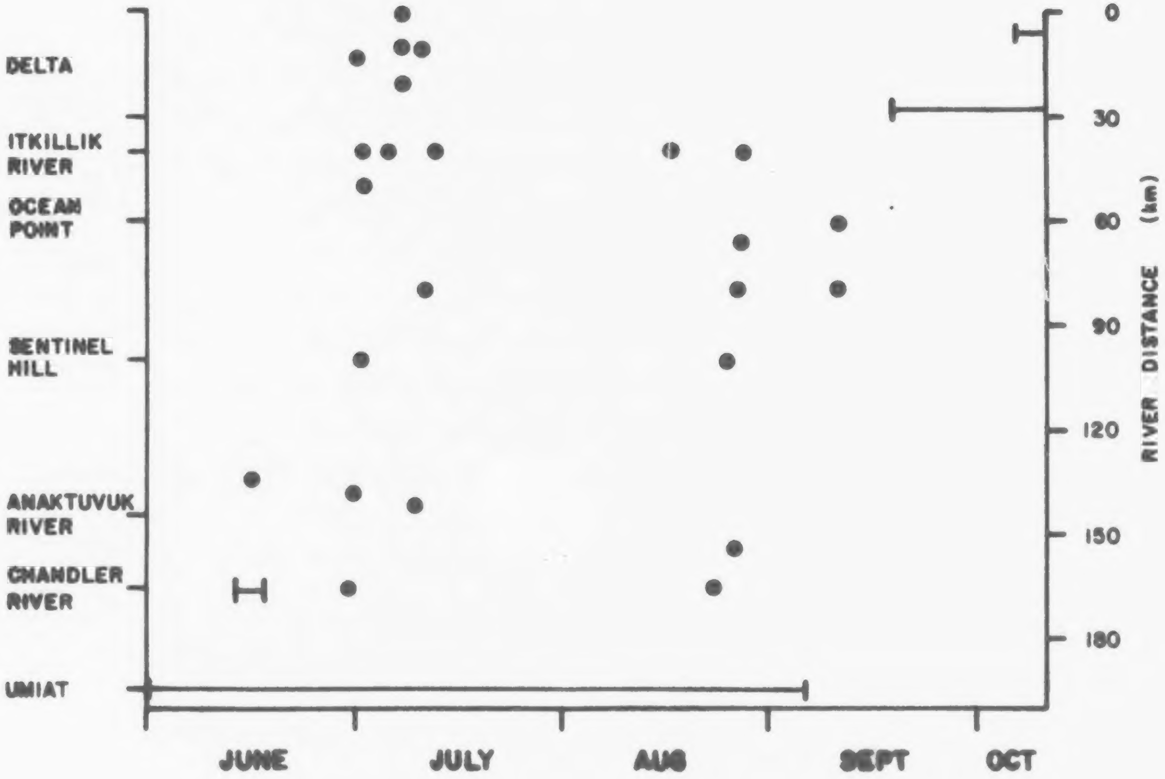

Figure 4. Dates of fish surveys conducted by various researchers along the Colville River downstream from Umiat. Dots indicate short duration samples while bars indicate longer-term sampling programs.

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Movement') also indicates the potential for rapid upriver migrations. Another feature of the river collections was that, with the exception of the Itkillik River, late summer collections were taken from the lower reaches of the rivers only. Thus, any fish moving above the mouth of the Anaktuvuk and Chandler rivers by this time would pass unnoticed.

A final point is that arctic cisco populations in other rivers apparently spawn in tributaries. In the Mackenzie River, specific spawning grounds are not known. Pre-spawning fish enter the Arctic Red and Peel rivers in late August, and it is suspected that they also enter the Great Bear River (Stein et al. 1973; Jessop and Lilley 1975). In Siberia, pre-spawning arctic cisco are also found in tributaries off the mainstream (Berg 1957).

CONCLUSIONS

Surveys were conducted in 1978 and 1979 to locate the spawning grounds of anadromous arctic and least cisco which inhabit the Colville River. Data from these and previous surveys indicate that least cisco spawn in the lower reaches of the drainage; fish in or nearing a spawning condition were collected in the Colville downstream from Ocean Point, in the delta and in several coastal lakes. Locations of arctic cisco spawning sites remain unknown. Based on the available information, it appears unlikely that this species spawns in coastal lakes, the Colville Delta or areas above Umiat. If arctic cisco do indeed spawn in this drainage, spawning may occur in large tributaries or the mainstem between the delta and Umiat.

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